architectuRe for an Internet For Everybody

D4.1: First Report on Technology Validation

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Abstract
This document describes the RIFE technical and socio-economic Key Performance Indicator (KPI) metrics as well as the technical and socio-economic evaluation scenarios. The document showcases the results from the intermediate technology validation with the focus on (1) the fronthaul ICN dissemination strategy using both the simulation and emulation platform, (2) the push/pull-based satellite Edge caching mechanism using the emulation platform, and (3) the RIFE reference configuration as an initial market approach.

Keywords
Information Centric Networking, Dissemination of Information, Multicast, Caching, Low-Cost Networking, Satellite, Alternative Network Deployments
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*R: Document, report (excluding the periodic and final reports)
DEM: Demonstrator, pilot, prototype, plan designs
DEC: Websites, patents filing, press & media actions, videos, etc.
OTHER: Software, technical diagram, etc.
EXECUTIVE SUMMARY

This document describes the RIFE technical and socio-economic Key Performance Indicator (KPI) metrics as well as the technical and socio-economic evaluation scenarios. The document showcases the results from the intermediate technology validation with the focus on (1) the fronthaul ICN dissemination strategy using both the simulation and emulation platform, (2) the push/pull-based satellite Edge caching mechanism using the emulation platform, and (3) the RIFE reference configuration as an initial market approach.

This document in particular presents the initial design and evaluation of the fronthaul ICN dissemination strategies mainly focused on a new multicast forwarding technique as well as a discussion on the use case for the backhaul dissemination strategy. The document also describes a network capacity usage model relevant to the RIFE system deployment. The document finally presents a qualitative, technical evaluation of the RIFE technologies from a socio-economic perspective. The obtained results are used as the starting point of the socio-economic validation to be included in deliverable D4.2: Report on Socio-Economic Validation.
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## ABBREVIATIONS

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<td>API</td>
<td>Application Program Interface</td>
</tr>
<tr>
<td>CPE</td>
<td>Customer Premise Equipment</td>
</tr>
<tr>
<td>CPU</td>
<td>Central Processing Unit</td>
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<tr>
<td>DTN</td>
<td>Delay Tolerant Network</td>
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<td>ECS</td>
<td>Edge Cache Server</td>
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<tr>
<td>FAP</td>
<td>Fair Allocation Policy</td>
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<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
</tr>
<tr>
<td>GW</td>
<td>Gateway</td>
</tr>
<tr>
<td>HHI</td>
<td>Herfindahl–Hirschman Index</td>
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<tr>
<td>HTTP</td>
<td>Hyper Text Transfer Protocol</td>
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<tr>
<td>ICN</td>
<td>Information Centric Network</td>
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<tr>
<td>ICT</td>
<td>Information Communication Technologies</td>
</tr>
<tr>
<td>IoT</td>
<td>Internet of Things</td>
</tr>
<tr>
<td>IP</td>
<td>Internet Protocol</td>
</tr>
<tr>
<td>ISP</td>
<td>Internet Service Provider</td>
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<tr>
<td>KPI</td>
<td>Key Performance Indicator</td>
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<tr>
<td>LAN</td>
<td>Local Area Network</td>
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<tr>
<td>NAP</td>
<td>Network Attachment Point</td>
</tr>
<tr>
<td>NGO</td>
<td>Non-governmental Organisation</td>
</tr>
<tr>
<td>QoE</td>
<td>Quality of Experience</td>
</tr>
<tr>
<td>RTP</td>
<td>Realtime Transport Protocol</td>
</tr>
<tr>
<td>SATLAN</td>
<td>Satellite Local Area Network (RIFE solution 1)</td>
</tr>
<tr>
<td>SBA</td>
<td>Scalable Bit Array</td>
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<tr>
<td>SDN</td>
<td>Software Defined Network</td>
</tr>
<tr>
<td>TCP</td>
<td>Transmission Control Protocol</td>
</tr>
<tr>
<td>UDP</td>
<td>User Datagram Protocol</td>
</tr>
<tr>
<td>URI</td>
<td>Uniform Resource Identifier</td>
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<tr>
<td>VNC</td>
<td>Value network configuration</td>
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<td>WISP</td>
<td>Wireless Internet Service Provider</td>
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INTRODUCTION

The RIFE project aims at providing sustainable Internet access to everyone, considering both the technical and the economic aspects of affordable Internet access. The technical aspects are focused on building novel ICN dissemination strategies in both the fronthaul and backhaul as well as harnessing technologies such as novel Edge caching solutions. The economic aspects explore how RIFE can enable new models for revenue creation for currently underutilised infrastructure allowing current business stakeholders to expand their revenues.

This document describes the RIFE technical and socio-economic Key Performance Indicator (KPI) metrics as well as the technical and socio-economic evaluation scenarios. The document showcases the results from the intermediate technology validation with focus on (1) the fronthaul ICN dissemination strategy using both the simulation and emulation platform, (2) the push/pull-based satellite Edge caching mechanism using the emulation platform, and (3) the RIFE reference configuration as an initial market approach.

The remainder of the document is structured as follows: Section 2 discusses the KPIs that will be used in the RIFE project and the technical as well as socio-economic KPIs are both discussed. In Section 3, we present the initial design and evaluation of the fronthaul ICN dissemination strategy mainly focusing on the new multicast forwarding technique using Scalable Bit Arrays (SBA) as well as a discussion on the use case for the backhaul dissemination strategy. Section 4 presents a network capacity usage model relevant to RIFE system deployment. The developed model and its parameters are flexible and can be reconfigured based on the realistic Internet usage data set such as the data set obtained within Guifi.net system. Finally, in Section 5, we present a qualitative, technical evaluation of the RIFE technologies from a socio-economic perspective. The obtained results are used as the starting point of the socio-economic validation to be included in D4.2: Report on Socio-Economic Validation.
KEY PERFORMANCE INDICATORS

This chapter presents a set of KPIs that will be used to verify the efficacy of the RIFE platform from a number of perspectives based on a number of use cases. Following the structure utilized in the POINT project\(^1\), the KPIs are categorized into flow-level, application-level, operational, network cost, competition and subsidy. For each specific KPI, we explain why it is needed, how it can be measured and to which scenarios it applies. In later versions of the WP4 deliverables, we will add specific target values for each KPI, which may be different for each scenario for which the KPI is relevant. For a number of KPIs being defined, we adopt the ones defined in the POINT project, specifically deliverable D2.1: Scenarios, Requirements, Specifications and KPIs. This is to align our view of network performance evaluation to that of POINT due to the similarities of the innovation space, specifically in fronthaul routing, caching and service endpoint placement, while adding system level KPIs that specifically relate to the RIFE innovation areas of new business models for operators.

In addition, the network cost, competition and subsidy KPIs are considered socio-economic KPIs. These define a framework to assess the ability of the RIFE platform to deliver affordable services. The framework states that service affordability is maximized when the following targets are achieved: (1) the minimum network cost, (2) the minimum operator profit and (3) the maximum subsidy. These targets are measured by the mentioned socio-economic KPIs.

2.1 List of KPIs

2.1.1 Flow Level KPIs

This category includes the most traditional KPIs, consisting of end user oriented performance metrics measured on a per-flow or a per-link basis.

**How to measure**: Since the endpoints for most of our scenarios are unmodified terminals running a vanilla TCP/IP stack, in the evaluation work we can rely on existing tools such as iperf and D-ITG for quantifying flow-level KPIs.

2.1.1.1 Mean Achieved Throughput

This is a central KPI for long-term downloads (software updates) and background updates such as content pre-caching plays a major role for on-demand video user-experience.

**How to measure**: Throughput can be measured using a number of widely available test tools available to the project.

**Use cases**: Education, e-Health, Disaster Management, Political awareness, Experience Sharing.

\(^1\) [https://www.point-h2020.eu/]
2.1.1.2 End-to-end latency
This is the main KPI for real-time interactive applications such as voice calls, control applications (including online gaming), as well as for general interactive web browsing experience.

How to measure: Latency can be measured using a number of widely available test tools available to the project.

Use cases: Education, e-Health, Disaster Management, Political awareness, Experience Sharing.

2.1.1.3 Packet Jitter
This is a major KPI for real-time interactive media applications such as voice calls, with influence on the efficiency of higher layer congestion control mechanisms.

How to measure: Jitter can be measured using a number of widely available test tools available to the project.

Use cases: Education, e-Health, Disaster Management, Political awareness, Experience Sharing.

2.1.1.4 Packet Error Rate
This is a major KPI for real-time interactive applications such as voice calls, control applications (including online gaming), with influence on the efficiency of higher layer congestion control mechanisms.

How to measure: Packet error rate can be measured using a number of widely available test tools available to the project.

Use cases: Education, e-Health, Disaster Management, Political awareness, Experience Sharing.

2.1.1.5 Frequency and Duration of Outages
This is a major KPI for video streaming and gaming, as outages interfere with the whole user experience.

How to measure: This KPI will be validated via existing network monitoring/management tools.

Use cases: Education, e-Health, Disaster Management, Political awareness, Experience Sharing.

2.1.2 Application Level KPIs
This category consists of KPIs which, as for the flow-level APIs, are measured at the end user level, but incorporating information on the level of user satisfaction on the performance of a particular application. Thus, they are measured higher in the stack than the classical flow-level KPIs. Perhaps the most important subcategory is time to
render KPIs (or time until initial access), consisting of the latency between an initial service request (entering a URL specifying a video stream to access, etc.) and the first content-related rendering on the user terminal. These metrics are highly sensitive to the network architecture used, as they are heavily influenced by the location of the content (caching, CDN placement), initial handshakes, security establishment, etc.

Another major category consists of perceptual metrics such as perceived video and voice quality. Those are in particular influenced by the joint behaviour of the codec, network, available transcoding services, etc. Again, existing tools can be used for measuring these, but at least in academic research the selection of tools is much less canonical. For specific scenarios, instrumenting websites with Google analytics tools might be a possibility, while browser plugins designed for performance analysis of websites is another possibility.

2.1.2.1 Web browsing performance

Performance is the main KPI influencing the interactive browsing experience for users connecting to the Web through the ICN network.

**How to measure:** A set of measured latencies and associated service delays will be compared against key latency constraints. For transparency, the sources will be broken down into, for example, the latency of individual contributions, and these will be reported alongside the aggregate numbers.

**Use cases:** Education, e-Health, Disaster Management, Political awareness, Experience Sharing

2.1.2.2 Audio and Video Quality

Streaming audio or/and video content between two end points, e.g., Spotify, YouTube, Skype or Hangout, accounts for more than half of the generated traffic of mobile end users with video content dominating the analysis at around 45% [ERI2015]. Therefore, from an application RIFE point of view, it is important to judge the quality of the stream.

**Use cases:** Education, e-Health, Disaster Management, Political awareness, Experience Sharing

2.1.2.3 Percentage of service requests solved over time

The resolution of requests on an ICN network has the potential to offer improved service KPIs, for example by sending requests to an appropriate local cache. However, the resolution itself introduces a small delay. It is important that the resolution phase is suitably fast for a given application, when the system is operating at a large scale. It is also important for the perception of users, to not observe significant fluctuations in the creation time of services (provisioning time) over a longer period.

**How to measure:** Even though individual users have different usage habits, when taken as an aggregate, the majority of people generate quite precise and coherent patterns. This KPI will measure the service request latency in a test scenario appropriate to the
use case studied, with typical user profiles for the range of competing services. The measurement will profile the distribution of service request times, in addition to simple metrics such as absolute maximum, fraction exceeding service maximum request time and mean service request time.

**Use cases:** Education, e-Health, Disaster Management, Political awareness, Experience Sharing

2.1.2.4  **Meeting user capacity demands**

Users judge the quality of a network based on long-term observations.

**How to measure:** Based on global traffic patterns reported in technical reports, a simulation/an emulation/ a modelling approach can be derived to determine how well the RIFE solution deals with real-world scenarios.

**Use cases:** Education, e-Health, Disaster Management, Political awareness, Experience Sharing

2.1.2.5  **Time to repair a service**

Enabling service resilience and distributing the load over several servers has been the answer of content providers to the end-to-end communication approach in contemporary IP networks. In an all ICN environment, the network natively supports the possibility to switch between content sources without communicating with the sink (subscriber). Hence, the time to repair a service (e.g., flow interruption due to a hardware failure on publisher) in an ICN network is another important application level KPI.

**How to measure:** A server failure will be emulated by disconnecting the publishing network element and measuring the time required to recover the service.

**Use cases:** Education, e-Health, Disaster Management, Political awareness, Experience Sharing

2.1.3  **Operational KPIs**

This category shifts focus from the end user to the network operator. The KPIs informs about the nodes operational performance and links which are critical in the hierarchy of the network architecture.

2.1.3.1  **Overhead for communication and service management**

Modern secure session protocols impose the usage of different encryption key for each user. Therefore, caching or request aggregation is not possible. For state management, the amount of overhead needed may affect the freshness of the state. Moreover, signalling overhead may degrade the quality of the offered services.

**How to measure:** The network overhead will be measured when multiple users request the same piece of content over a secure connection, as well as the number of records
and messages required for maintaining the proper state.

**Use cases:** Education, e-Health, Disaster Management, Political awareness, Experience Sharing

### 2.1.3.2 Router CPU overhead per video stream

The CPU overhead in a software router will be measured.

**Use cases:** Education, e-Health, Disaster Management, Political awareness, Experience Sharing

### 2.1.3.3 Number of supported video streams per user

IP multicast requires per-channel state in each router, while RIFE uses stateless multicast, therefore, the number of video streams that can be supported is limited by available fast memory.

**How to measure:** Calculate memory requirements in software routers to determine capacity.

**Use cases:** Education, e-Health, Disaster Management, Political awareness, Experience Sharing

### 2.1.3.4 Number of supported video streams per server

Adaptive streaming requires unicast transmissions to each individual client, thus limiting the possible subscribers per server, while RIFE may combine synchronized or quasi-synchronized subscribers via multicast, in order to reduce load.

**How to measure:** Calculate memory and CPU requirements in servers to determine capacity.

**Use cases:** Education, e-Health, Disaster Management, Political awareness, Experience Sharing

### 2.1.3.5 Per hop packet transmissions per IP multicast packet

**How to measure:** Analyse the packet duplication in test graphs, possibly simulation, to account for transient inefficiencies (as users switch channels).

**Use cases:** Education, e-Health, Disaster Management, Political awareness, Experience Sharing

### 2.1.3.6 Per hop packet transmissions per adaptive streaming packet

**How to measure:** Analyse the packet duplication in test graphs, possibly simulation to account for transient inefficiencies (as users switch channels).

**Use cases:** Education, e-Health, Disaster Management, Political awareness, Experience Sharing
2.1.3.7  Link utilisation efficiency

The combination of traffic awareness that helps prioritization, and capacity management techniques (e.g., multicast, caching), will allow higher priority traffic and more traffic in general to cross each link.

**How to measure:** Measure the weighted link capacity (based on priorities) for certain ICN scenarios and compare with typical IP operational measurements.

**Use cases:** Education, e-Health, Disaster Management, Political awareness, Experience Sharing

2.1.3.8  Service availability

The RIFE platform components should be available more than x% of the time.

**How to measure:** Measure recovery time versus expected service availability.

**Use cases:** Education, e-Health, Disaster Management, Political awareness, Experience Sharing

2.1.3.9  Mean time to failure

A service should have high intervals between failures.

**How to measure:** Measure time between failures

2.1.3.10  Level of automation of network management

Managing a service should be as automatic as possible.

**How to measure:** Measure the number of manual steps in set-up and change of service.

2.1.4  Network cost KPIs

These KPIs allow the comparison of costs between different network architectures. For example, ICN-enabled versus standard IP.

2.1.4.1  Number of nodes and links

The more network devices are required in the network architecture, the more costly this becomes to build, maintain and manage.

**How to measure:** Calculate the average number of nodes and links required for the network architecture to serve a fixed number of users.

2.1.4.2  Characteristics of nodes and links (routing, computing and storage)

The network architecture requires protocols to perform the routing and storage of information. At the same time, computing power is required from nodes and links to perform these activities.

**How to measure:** Determine the required node capacity (e.g. CPU, memory, power consumption) and link coverage (e.g. 100m, 30 km) of the basic elements in the network architecture. The characteristics can be derived from operational KPIs.
2.1.4.3 Transmission cost

Transmission cost takes into account the data transmission via the network owned by the operator and via other operator’s network. In the first case, the transmission of information is highly dependent on the technology efficiency with respect to the medium (e.g. bits/Hz, bits/fiber). In the second case, the transmission cost equals the transit cost.

How to measure: Transmission cost via an operator’s own network is determined by the transmission efficiency of network technologies (e.g. bits/Hz in 802.11 at 2.4 GHz) as well as the required licenses to operate in the respective mediums (e.g. the 2.4 GHz band is an unlicensed). In a comparative analysis, only the changes in transmission mediums are relevant. Alternatively, the transmission cost via other operator’s network is derived from the transit contract conditions.

2.1.5 Competition KPIs

Market competition cannot be assessed directly because the network architecture is not yet in the marketplace. However, the network architecture itself might prevent competition to happen by unnecessarily favouring some actor, node or protocol. Given that the delivery of digital services (e.g. content delivery) require cooperation of multiple actors (e.g. content provider and network operator), the network architecture can be assessed with regard to the exchangeability of actors, nodes and protocols. In other words, the KPIs which validate that monopolistic behaviour is not favoured in the resulting industry architecture also known as value network configuration (VNC) [Cas2010]. We define a Value Network Configuration (VNC) as a set of business actors that provide one or more business roles by the execution of technical components and this way create value through services.

2.1.5.1 Inter-actor competition

The more business actors (e.g. network operator, content provider) who can adopt a business role (e.g. content provision), the more market competition exists in the network (e.g. in the content delivery market), the lower the profits, resulting in lower the consumer prices.

How to measure: The optimal calculation method estimates the Herfindahl–Hirschman Index (HHI) for each business role in possible value network configurations. In the context of a technical evaluation, this KPI can be assessed evaluating the technical requirements for actor exchangeability (e.g. the openness of protocols connecting partners in the value network configuration).

\[^{2}\text{HHI is calculated as the sum of the squared market shares in terms of number of subscriptions. Extreme values are 0 which indicates perfect competition and 1 which indicates monopoly.}\]
2.1.5.2 Inter-node competition

Business actors (e.g. network operators, service providers) compete in a fair manner if the network architecture allows traffic to be freely routed to optimize network performance. For example, low node competition might imply that a single operator could control the access to popular resources and therefore adopt monopolistic practices (e.g. increase in prices) and also increase the probability of network failure (e.g. overload in the single point of failure).

**How to measure:** Determine the technical components in the configuration that become business bottlenecks. Determine the points of failure and corresponding backup nodes and links.

2.1.5.3 Inter-protocol competition

The co-existence of protocols enables easy transition and fair competition between protocols. For example, a VoIP provider can offer services to ICN-enabled networks only if ICN is able to satisfactorily transport RTP/UDP. Another example is a provider or a customer that wants to access the original source of some content instead of the cached copy.

**How to measure:** Count the number of incompatibilities between well-known protocols (e.g. TCP, UDP) and the new protocols responsible for the network function. Identify the number of proprietary protocols.

2.1.6 Subsidy KPIs

The KPIs validate that the network architecture does not prevent stakeholders from subsidising the customer access cost or the provider cost. In case of direct customer subsidy, both the consumer segment (e.g. students) and the corporate segment (e.g. educational services) could access the network at better than market conditions. In case of provider subsidy, users are indirectly subsidised and providers might increase network capacity and coverage or introduce price reductions. A relevant aspect about subsidies is the expected payback time of subsidisers. For example, while the government typically subsidises at the long term (e.g. education increases productivity and investment is recovered via taxes), advertisers might expect a shorter payback time. More importantly, subsidisers might require accountability in order to quantify the investment payback rate. As a result, non-vital network services (e.g. accounting and billing) might be required and network cost increased accordingly.

2.1.6.1 Local government subsidy

Local authorities could subsidise users to promote a long-term economic or social policy at the local level, for example, the adoption of e-services (e.g. digital tax collection). These could also subsidise access costs of public service providers (e.g. libraries).

**How to measure:** It will be determined if the network architecture prevents such a subsidy (i.e. Yes/No).
2.1.6.2 National government subsidy

National authorities could subsidise users to promote a long-term economic or social policy at the national level. For example, the adoption of e-services (e.g. e-government including student registration, digital tax collection). These could also subsidise access costs of public service providers (e.g. schools, hospitals) or private strategical sectors (e.g. agriculture, tourism) to increase its capacity (e.g. via e-learning, tele-medicine, updated trade price information).

**How to measure:** It will be determined if the network architecture prevents such a subsidy (i.e. Yes/No).

2.1.6.3 Bank subsidy (Bank loan)

Financial organizations could subsidise users via micro-loans to promote productivity increase in the short term. Then, this would recover the investment in the long term from a more productive community.

**How to measure:** It will be determined if the network architecture prevents such a subsidy (i.e. Yes/No).

2.1.6.4 Advertiser subsidy (advertisement-based business model)

Advertisers could subsidise users if additional revenues could be quantified and associated in the short-term with user activity in the network. For example, an advertiser might directly or indirectly provide free data to users that consume a particular content that has associated a piece of advertisement.

**How to measure:** It will be determined if the network architecture prevents such a subsidy (i.e. Yes/No).

2.1.6.5 NGO subsidy

NGOs could subsidise users to promote a short-term economic or social policy. For example, and NGO might directly or indirectly provide free data to users that use e-learning applications.

**How to measure:** It will be determined if the network architecture prevents such a subsidy (i.e. Yes/No).

2.1.6.6 Volunteer subsidy

Volunteers might contribute with financial resources and/or free labour to acquire, build and maintain the network infrastructure. This might be the case of community operators that manage the network service as a common-good.

**How to measure:** It will be determined if the network architecture prevents such a subsidy (i.e. Yes/No).
3 TECHNICAL EVALUATION

3.1 Dissemination Strategies

In this section we discuss the fronthaul access to underserved communities and present the composition of the fronthaul technologies that will provide such a service in RIFE. We discuss the design and implementation of a zoning strategy, a technique to improve the scalability of PURSUIT [PURSUIT] in terms of increasing the total number of addressable links in a network. This section also discusses the use case for the backhaul dissemination strategy.

3.1.1 Fronthaul

3.1.1.1 Zoning

Fixing the native multicast in IP networks with overlay multicasting has proven to be inefficient [Jokela]. The routing operations in IP networks require advanced memory and packet switching technology resulting into a costly address translation. These costs make it difficult to cover the increasing demand for multicast services in data centers [Vigfusson]. Jokela et al. [Jokela] propose a partial solution to the above stated problem called LIPSIN. It has been proposed to remove multicast state in the routers and has been considered as an energy efficient solution. Nevertheless, authors show that it presents early limits in scalability in Pub/Sub environments, i.e., the number of false-positives transmissions increases with the number of subscribers. The increase of false-positives has undesirable effects, such as producing cycles in packet routing and wasting bandwidth.

In what follows, we discuss the design and early implementation results of an approach to increase the scale of link labelling in ICN networks, while maintaining the benefits of LIPSIN filters. Our intention is to get rid of false-positives altogether while increasing the scale of the total number of addressable links. We achieve this by dividing the network into zones and by proposing a new data structure and addressing a scheme named Scalable Bit Array. Preliminary simulation results show that we can safely scale up in real topologies, paving the way for future tests in Community Networks such as Guifi.net.

Potential Scenarios to Introduce Scalability

Among the different motivations to scale up the number of addressable nodes are:

1. Internet of Things. One of the recent major contributors to the growing flow of information on the Internet corresponds to the Internet of Things (IoT), i.e., low-cost, resource-constrained devices being deployed everywhere. With the emergence of the IoT paradigm, a significant number of devices are expected to be connected over IP-enabled networks (well known for not being conceived and being unfit for IoT networks) [Shang]. Similarly, there is recent interest in tackling the increase of on the scale data transmission and organization by using ICN
perspective on Edge networks. Therefore, ICN is used to avoid creating even more state in the network, and used to easily integrate easily the desired functionalities of IoT networks, such as caching, energy efficiency, and flexibility in the dissemination of information, etc.

2. **Video Streaming.** Video transmission over today’s IP networks mostly uses HTTP-level unicast to convey traffic to clients. This is the case for off-line and live video transmissions. In this scenario, the use of bandwidth is proportional to the number of users, thus creating an obstacle to a widespread deployment [Trossen1]. In a different view, the PURSUIT architecture allows for the efficient dissemination of multimedia content on top ICN primitives. The best example of the gains obtained by PURSUIT architecture are easily obtained from video dissemination, which Piro et al. [Piro] consider as the killer application for the POINT project.

**On the need for zoning**

As the forwarding efficiency of LIPSIN identifiers (due to Bloom filter properties [Bloom]) is noticeably affected after 20 subscribers attached to a single publisher [Jokela] (e.g., by wasting bandwidth, producing undesired loops, etc.). Many authors have proposed different techniques to attack the root of the problem, i.e., to bound the number of false-positives, thus simultaneously addressing the scalability of multicasting.

In order to scale up the multicasting, there is a rough consensus on splitting the network into several independent multicast groups. We also believe that such approach leads to a better performance in multicasting. Thus, we propose a novel zoning strategy (i.e., splitting the network) within in the PURSUIT ICN implementation named Blackadder (https://github.com/fp7-pursuit/blackadder).

Rizvi et al. [Rizvi] keep the bandwidth wastage below an acceptable threshold while scaling up the multicast tree to a large number of receivers. Authors split the multicast tree into smaller ones, which are encoded as separate Bloom filters. The proposed strategy increases 5x the efficiency of the Bloom filters by slightly increasing the state requirements in the sources.

Nikolaevskiy et al. [Nikolaevskiy] present an extensive evaluation of several techniques to overcome the limitations of Bloom filters on multicast communication. Similar to [Rizvi], authors fix a fill factor (FF) to avoid false-positives, and new groups are started once reaching the FF. This basic strategy is further improved with simple additions when topology information is available. For example, merging lexicographically (from a bit string perspective) close groups, combing topologically close destinations, and so on. The evaluation shows savings of up to 70% in traffic volume in large-scale topologies with big groups of subscribers and up to 30% for small groups.

Hao et al. [Hao] proposed a method for false-positive reduction called partitioned hashing. The method consists in choosing a hash function that set fewer bits in the Bloom filter bit vector, thus indirectly inducing a lower FF of the bit vector. Authors
report improvements of up to 10 times in accuracy (i.e., a significant reduction of false-positives), compared to regular Bloom filters.

Boivie et al [Boivie] propose a strategy for increasing the scalability in terms of different coexisting multicast groups (as specified in [RFC1112]). Authors propose Xcast, a new multicast scheme supporting a very large number of small multicast sessions. The increase in scale is achieved by encoding the list of destinations in the data packets. As the solution is intended for IP networks, authors do not address the use of Bloom filters. However, Xcast has been conceived to eliminate the per session signalling and per session state information in traditional IP multicast schemes, thus supporting very large numbers of multicast sessions, one of the primary motivations behind the Bloom filter proposal [Jokela]. Thus, the solution of Boivie et al. can be applied in scenarios in which a large number of small multicast groups coexist (videoconferencing, voice over IP, and Internet of Things, etc.).

**General Aspect of Design**

We considered the following design tenets for the proposed implementation of zoning in PURSUIT. These principles help in providing the design criteria within every zone (i.e. a sub-network) in a network. If deployed along with a partitioning algorithm (eventually hosted in the Topology Manager), the provided solution also gives a mean to mitigate the unavoidable processing overhead on poppers. Thus, the following general ICN Zoning goals are considered:

**A. Scalability.** The proposed solution supports any topology and group size. We introduce a flexible solution that allows increasing the number of nodes while preserving the benefits of fast forwarding match-up mechanism [Jokela]. In fact, during the network bootstrapping period, the deployment tool calculates automatically the LIDs for all links in the topology automatically. For later re-accommodations of the network, the Topology Manager provides the necessary mechanisms.

**B. Instantaneous multicast group dynamics.** Easily formed multicast trees are a highly desirable property of Bloom filter like identifiers, since ORing the unicast filters produces them and in our particular case, XORing unicast filters can safely exclude uninterested subscribers. Thus we keep this feature for instantaneous group dynamics within a zone, and we bound the resource consumption in the interzone multicast group formation guaranteeing the minimum cost when joining or separating two delivery trees.

**C. Simple forwarding.** We keep forwarding as simple as possible and compliant to the basic AND/CMP based forwarding. We mostly stick to a minimum, the overall increase of individual forwarding costs, i.e., the cost of inter-zone forwarding. When a popper connects more than two zones, there is an unavoidable higher cost for multiple zones checking on forwarding.
D. **False-positive-free forwarding.** As described by Sarella et al. [Sarella], legacy Bloom filter solutions suffer from false-positive forwarding potentially creating infinite loops in the network. We develop a solution that gets rid of false-positives while, different from existing solutions [Rizvi][Nikolaevskiy][Hao], we keep a low link-identification forming and forwarding complexity.

E. **SDN capable.** In order to ensure an easy deployment in emerging network environments, we adopt a straightforward popping scheme. Ongoing efforts (e.g., [Antikainen]) show that it is possible to implement an early version of a popper in a few hundred lines of code in a Software Defined network platform, thus accounting for low complexity in the adaptation of the solution to SDN environments.

**Design premises considering the implementation**

A. **Zoning an ICN network.** A zone in an ICN network consists of a set of unique link identifiers in a connected subgraph of the zonable network. Every link within a zone has to be addressable through a bit-array filter (BaF). Moreover, zones are connected with each other through special nodes called poppers in which adjacent nodes belong to different zones. Therefore, there must be an unambiguous way to connect two adjacent zones (see Figure 1).

B. **Minimal charge on the network.** The solution for scalability should minimally impact the routing overhead. That is, the popping operation should be performed as fewer times as possible and in less number of nodes, as possible. The former can be assured through the data structure used to carry all the concatenated identifiers upon which the data transformation (e.g, zoning or re-zoning [D3.1]) will be performed. The latter is less under the control of the implementation details, however we have opted to use a zone naming scheme as a strategy to uniquely identify multiple zones.

C. **Popper as a function on any forwarder.** Given the dynamic nature of the initial network topological organisation and reorganisation (throughout its life), we have to consider the popping function potentially as part of any node in the network (refer to [D3.1]). This situation implies that the selected node may also execute regular forwarding functions in the network (see Figure 1). Thus, the popping or forwarding function will be easily elucidated by assigning a different LID (namely pLID) to the popping function.

Figure 1 is an example in which a popper node P1 (exceptionally) forwards messages within the same zone Z1. The figure depicts three zones Z1, Z2 and Z3. Z1 and Z2 have two poppers in common, and the dual function of the popper is observed when the popper P1 acts as a forwarder towards Z3. Thus, P1 should forward the message to reach the popper P2 in order to reach finally Z3. We could easily mistake that a message carrying piggybacked zones is an indication to pop a new zone, however, this is precisely the case in which an indication for using pLID per popper will make a clear distinction.
D. Unique Identification of in-zone Links. To implement a scalable dissemination strategy in an ICN network, we propose the use of an identification strategy mappable into a data structure that we call Scalable Bit Array (SBA) that allows to uniquely identify each node in the network uniquely.

Through an SBA we can represent as many zones as needed within an ICN scenario (we show that 4 bits are enough on realistic topologies, refer to Section 3.1.1.3). The SBA for a single network would contain all the possible identifiers needed for disseminating information. Its form and configuration will depend on a given partition scheme and the subsequent modifications on the topology such as obeying certain traffic characteristics, and resiliency needs, etc. (see [Antikainen][Boivie]). The SBA data structure also depends on a garbage collection system that accounts for both used and available identifiers to guarantee bounded times to perform the split, join, as well as the register operations within zones (see [D3.1] for details on zoning scenarios).

3.1.1.2 Zoning a Network

Problem definition. Having to attend the design premise (D) (of having unique identification of every link within a zone), a popper faces the problem disambiguating among different next zone filters unless there is a clear connecting strategy between two or more consecutive zones. This is a consequence of having all filters with a similar structure. Thus, we need to assure enough state within each filter so that it can be uniquely matched with the next required zone. As seen in Fig 3.2, with a simple bit-array (with one bit denoting one link) a popper leading to two or more zones would not be distinguished by inspecting an (eventually non-identified) BaF containing the next zone filter. As can also be derived from the Figure, if the message was coming from Z1, it has to be simultaneously copied to zones Z2 and Z3, the popper would again be unable to decide which BaF matches which zone. Additionally, it is highly desirable that a BaF has as many available bits as possible making this requirement a good case for introducing a new field called ZID to identify each a zone.
3.1.1.3 On zone identification

The above stated problem can be initially tackled with Zone Identifiers (ZIDs) that can be written into the first X bits of a bit-array filter. The following observations derive from the problem statement:

A. There has to be a unique way of retrieving piggybacked zones carried within a message. We are aware that retrieval problem can be solved either by having a unique key identifier, i.e., a Zone ID, or by having a predictable order in the piggybacked list of filters (e.g., a tree traversal strategy). We have opted for the former approach since it is a simpler strategy regarding terms of implementation effort and economy of space in the BaF.

B. Let’s explore the possibility of having a predictable order in the piggybacked filters to hand messages to other zones. Then it is necessary to have as many links as there are adjacent nodes to any popper (see Figure 3). This condition will take an unnecessary number of LIDs per link, i.e., as many as existent inter-zone routing directions. The total number of LIDs corresponds to the number of adjacent nodes times the total of connected zones. So from the example of Figure 3, a total of 3 links x 3 zones = 9 LIDs have to be used. This distribution can be observed in Figure 3 as we consider a publisher placed in different zones. In this particular case, the LIDs belong to the zone in which the publisher resides.
Let’s assume now that we use ZIDs (see Figure 4). For every BaF having ZIDs allows the saving of extra LIDs being unnecessarily spent elucidating the next zones during a popping operation, and allows the popper to execute a simple algorithm to put the correct BaF in front of the message.

![Bit array filter structure](image)

**Figure 4: Bit array filter structure**

On a message received in a popper, the actions taken are:

1. Current zone filter must activate the popping function
2. Account the piggybacked zones in the multicast message
3. Match up the accounted zones with the interfaces marked with ZIDs
4. Put the correct BaF in front of a message
5. Deliver the message into all next Zones

From the previous algorithm we can observe that an active BaF needs only to contain LIDs from the current zone. This design premise represents a savings in the number of LIDs to identify adjacent links to a popper. Observe in Figure 5 that for every direction of the transmission, there is no need to assign different LIDs per popper’s adjacent link.

![Avoiding multi-labelling when using zone IDs](image)

**Figure 5: Avoiding multi-labelling when using zone IDs**

Let’s walk through an example to see how the zoning strategy works. In Figure 6 we present a simple zoning that shows how the popper A can distinguish between messages going from publisher P1 to subscriber S1 and messages going from P2 to S2. Notice that this two message interchanges occurs in opposite directions. For the sake of clarity, adjacent links to a popper are depicted as dashed lines. When P1 sends a message to S1, the current zone filter in Zone 100 is \{1,3,Pop\}. Once the message gets into popper A, it looks for the piggybacked filter \{ZID: 011, 3,6\} and forwards the message to Zone

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3 Without loss of generality, we do not address the case of wireless networks.
011 with the new current zone filter \{3,6\}. A similar procedure will occur in the opposite direction when P2 sends a message to S2 \{ZID: 011, 1, 6, 3, pop\}, \{ZID: 100, 3, 1, 2\}.

![Diagram](image)

**Figure 6: An example of the zoning strategy**

### 3.1.1.4 Scalable Bit Array

A scalable bit array (SBA) is a data structure for abstracting the labelling of edges in a graph. It has the properties of a simple bit array, however it is intended to be managed by a central entity called *Big Indexer* in which every bit uniquely addresses (or identifies) a different edge of a graph. This data structure is intended to host a convenient representation of the labels for edges in a graph, so that join and disjoin operations are easily performed when reorganising the zoning of a network.

The SBA allows two main operations. First, it allows the representation of the whole set of network edges and controls the availability of the labels. Second, it contains the logic for the building of a series of properly ordered and concatenated BaFs, representing a delivery tree. We remark that a delivery tree is composed of at least one zone BaF or zBaF and eventually, a concatenation of one or more bit-arrays (cBaF) including other zones of the graph.

**Design**

Figure 7 shows the data structure consisting of a *Big Indexer* containing a representation of the network topology. Every bit-array has an associated binary index, corresponding to the Zone ID (ZID). As further observed in the Figure 7, the two binary indexes 001 (1 dec) and 010 (2 dec) have identical bit-array components, however they are uniquely identified by the so-called binary index. There are \(2^x\) possible zones within a single SBA, where \(x\) corresponds to the number of bits for the binary index. Within the indexing function, each bit-array represents the status of the labels being used during the SBA life, i.e., it accounts for the active links indicated by a particular bit (marked as 1) as well as the free ones (marked as 0). The interface of the data structure offers methods in
order to obtain a new identifier within a zone or to dispose of it after it has been used (e.g., when shutting down a link).

![Figure 7: The Scalable Bit Array](image)

There is a fundamental difference between the binary index and the bit-array: the binary index is intended to abstract a smaller portion of the network corresponding to the inter-zone connection. Observe that the overlaying inter-zone graph may allow fulfilling different objectives of the transmission, e.g., traffic balancing among different zones. As seen in Figure 7, there is no connection from Zone 010 to Zone 011, so a path can be constructed either passing through Zone 001 or through Zone 100. On the other hand, the BaFs work for in-zone routing.

**In-zone identifier**

![Figure 8: Bit-array filter (BaF)](image)

As shown in Fig 3.8, a bit string is the primary building block of an SBA and it is intended to store a set of unique identifiers in the bit-array portion, which is preceded by the binary index or Zone ID. The binary index corresponds to a pre-established number of bits acting as unique identifiers for the in zone edges and paths. So, given a bit string of size N, we enforce the following general field repartition.

As suggested by Yang et al. [Yang] and later by Antikainen et al. [Antikainen], Elias Gamma encoding (EGE) can save space on a BaF whenever the number of used bits are small enough. Thus, EGE adds the possibility of compressing a BaF. However, when the number of subscribers increases, EGC may just add an overload to the multi-zoning scheme.

For a compressed representation, the total number of bits using EGE is: $2\lfloor \log_2 x \rfloor + 1$, with x as the number of bits representing the number of possible zones.

Then the remaining $E = N - (2\lfloor \log_2 x \rfloor) + 1 + x - 1$ bits will correspond to the total number of bits available for identifying the elements. Note that E also denotes the maximum size of the subset to be represented.

The characteristics of a scalable bit array are as follows:
• A bit string easily extensible/modifiable bit string by rearranging the different components

• A maximum number of addressable elements bounded by the deliberate choice of N and x, resulting in \( E = N - (2\lfloor \log_2 x \rfloor) + x \)

Thus, as shown in Figure 9, the total number of addressable edges in the network is \( T = E2^{N-1} \), i.e., with 10 bits we can address about 200,000 unique IDs in up to 1024 zones.

![Figure 9: Total number of addressable nodes considering the proposed distribution](image)

**On the Blackadder extension**

For the Blackadder [BLACKADDER] zoning extension, we have divided the implementation work into three stages: (1) zone marking in the deployment tool, (2) incremental implementation in Blackadder core (3) upgrading the Topology Manager to deal with zones. We observe that the design of a proper data structure to identify all zones and links, and eventual network partition strategy, is a transversal for all three tasks.

**A. Zone Marking (in Deployment tool).** We pretend to adapt the zone definition scheme as in libconfig [http://www.hyperrealm.com/libconfig/], an open, compact, XML-like markup format to specify the configuration and distribution of the network definition in Blackadder. It will allow us to determine a new popper role in Blackadder. During the ICN network bootstrapping, the popper role will be assigned to the designated forwarder.

The popper click module can be easily incorporated only to certain poppers during the deployment phase. Blackadder is implemented using click modular router framework [CLICK]. This framework allows ease of design, extension, maintenance and implementation of new features for PURSUIT Blackadder. The popper functionality is going to be implemented as a click module and thus can be effortlessly activated in any forwarder node.
LID Assignment. As a design principle, we have decided to rely on a fixed length bit-array to identify all nodes within a zone. Whenever the number of needed LID exceeds the total number of available bits, then a new bit-array is used to determine a new zone. For the time being, the length is a hard-coded decision before deploying the Blackadder network. As the end user uniquely labels each node, the initial assignment of the LIDs can rely on the identification of the nodes from which the Topology Manager can calculate unique paths.

B. Incremental implementation in Blackadder core. We are incrementally implementing the zoning strategy in Blackadder. In this document, we show the initial results on the impact of a zoning strategy on Blackadder routing scheme.

C. Upgrading the Topology Manager. The Topology Manager holds a global vision of the network. Starting from deployment of a Blackadder network, the TM should be able to keep track (e.g., update) of the topology dynamics and to match up publishers and subscribers. The later requirement deserves prompt attention since it directly uses the critical path calculation algorithm, which needs to compute the multi-zone traversal.

Data Structures at the Topology Manager. We need to extend the graph management igraph [IGRAPH] and incorporate our proposed zoning strategy.

Blackadder node architecture
As a first iteration on the implementation of a zoning strategy in Blackadder, we have identified the critical path on the implementation of a PURSUITB Blackadder [BLACKADDER] node when announcing a subscriber to the rendezvous node (RVZ). Typically, during the bootstrapping phase, a subscriber needs to announce itself to the RVZ node, which for our implementation (prototyping level) purposes, we have placed in a different zone. Our intention is to explore the critical (minimum) path of a single message, leading us to understand the integration of a popper in Blackadder.

Figure 10 shows the topology used for our tests. There are two zones interfaced by a single popper. A subscriber living in the green zone, issues a SUBSCRIBE_SCOPE message directed to the RVZ residing in the blue zone.

Figure 10: Testbed for initial testing of popper function
Figure 11 shows in more detail the different components of a subscriber and a forwarder. This architecture also describes a popper. The popper node has been implemented as a minimal modification of the PURSUIT code. As shown in this Figure, the subscriber sends a scope subscription request, transporting the two ICN function indications: `<DOMAIN_LOCAL, SUB_SCOPE>`. The `DOMAIN_LOCAL` indication corresponds to the dissemination strategy (forcing an inter-forwarder routing to reach the rendezvous function), and `SUB_SCOPE` denotes the required pub/sub function. The network message is generated from the subscriber through the regular interface:

```cpp
#include "blackadder.hpp"
...
ba->subscribe_scope(scope_id, scope_prefix, DOMAIN_LOCAL, NULL, 0);
```

In the following scenarios, we present the different cases of a message traveling in the proposed testbed of Figure 10.

**From the subscriber to the forwarder.** The subscription message is sent to the forwarder through local sockets interface. As shown in Fig 3.11, the module `FromNetLink` gets the message from the subscriber process and hands it to the `LocalProxy` module. This module is in charge of dispatching all messages to all the components of a Blackadder node; however, we have depicted a critical path in which the different popper functions will take place.

Assuming that the filter to reach the popper in the second zone has been calculated prepared, the node knows the multi-zone RVZ address through the `GlobalConf` module. The function `LocalProxy/handleLocalRequest` will make possible the storage of the
current subscription request in a special table containing active subscriptions under the forwarder.

Finally, the subscription request is handed to LocalProxy/publishReqToRV which will construct the packet and will send it to the next node. As specified in the topology Figure 10, the next node corresponds to the popper.

**From the forwarder to the popper.** As can be seen in Figure 11, once the subscription message arrives at the popper, it reconstructs the list of piggybacked zones and selects the correct one within the receiving function. Observe that the message comes through the “IN” interface, i.e., from a network socket.

The piggybacked zone is extracted from the incoming message through the convenient interface of the BaF object. So, after initializing the SBA object with the raw bit string, the popping of a zone is a simple method call:

```c
// declare an empty scalable bit array
SBA incoming_sba;
// filling up the sba
incoming_sba.fill_up_SBA((char *)p->data());
// …
// popping a new zone
incoming_sba.pop();
```

**From the popper to the destination.** Once the piggybacked zone is placed in the front of the packet, the forwarder node can check upon the forwarding table and dispatch the packet to the required zone after proper inspection on the list of piggybacked zones. In the destination node, the matching between the filter and iLID will result positive, thus conveying the subscription request to the RVZ node.

### 3.1.1.5 Initial evaluation of popper operations

To evaluate the impact of the popper function in the system we have tested a simple scenario specified in Figure 10 and intended to test conditions as the ones shown in Figure 12.

![Figure 12: Representative scenario for the initial evaluation of the impact of popper operation](image)

We show the initial performance tests showing the impact of the zoning strategy in PURSUIT. We scale up the number of poppers and present the implications in the two critical parts of the system. In both scenarios we increase the total number of zones as
1, 5, 10, 20 and 40 and assuming that the BaF cannot be compressed (e.g., because each zone has enough nodes to address).

Figure 13 shows the zoning strategy impact on the local processing scenario, from the subscriber to the forwarder. There are two main consequences of the zone message setup. The first setup is the base cost of the Scalable Bit Array data structure. As can be seen in the single zone measures, the cost increase from 10 us (PURSUIT reference) to 100 us is due to the sending of the subscription message to just before sending it to the network interface. The second setup is the incremental cost of piggybacking zones up to (near) the MSS capacity (i.e., packets of 1280 bytes just transporting zones). We observe that on average every zone identifier (of 32 bytes) increases the processing time by approximately 23 us.
Figure 14 shows the zoning strategy impact on the networking-processing scenario, from the forwarder to the popper. Once the message goes out of the network interface of the forwarder (hosting the subscriber), it is sent to the popper. The processing time shown in the Figure corresponds to the time it takes for the popper to build the SBA structure with the received message and to perform the popping operation. We have measured different quantities of popping operations as suggested by Figure 12. However, we do not account for the inter popper transmission time since it is more predictable and depends on the NIC technology.

Observing the minimal case of 1 piggybacked zone, the cost of introducing the zoning strategy is minimum at the popper. It goes from approximately 80 us (as regular message reception in PURSUIT) to about 150 us when extracting the unique piggybacked zone. Further experimentation considers transporting 5, 10, 20 and 40 zones. The crosses indicate the cost of popping all of them so as to have an idea of an upper bound. Later, we measured the cost of popping half of the zones while keeping the same number of piggybacked zones, i.e., for ten (10) piggybacked zones, five (5) were popped and so on. Surprisingly, the cost of the popping operation seems to be negligible with regard to the cost of processing the message and building the SBA. This is observed when the dashed lines keep bounded by the crosses.

### 3.1.1.6 Evaluations: Scaling up network identification – A simulation perspective

The simulation results are driven by a balanced edge partition problem, as a first approximation of how the proposed zoning strategy behaves. The naming convention

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Figure 14: Impact of the zoning strategy on the networking scenario, from the forwarder to the popper

![Graph showing impact of zoning strategy on networking scenario](image_url)
assures the instantaneous group formation. Similarly, our strategy is compliant with the simple forwarding. Finally, SDN capability is left for future assessment.

**Simulation system model**

SBA forwarding scheme is designed for wide scale intra-domain multicast. The scheme can work in networks where roughly half of the switches can perform packet matching on arbitrary fields (e.g. software switches or P4-switches) while the rest of the switches can be regular OpenFlow switches. We assume a network that can be represented as a directed graph, $G_n = (V_n, E_n)$, where $V_n$ is the set of switches and $E_n$ is the set of links.

The basic idea in SBA is to group the network edges into partitions so that every partition contains at most 256 edges. Then, every partition is allocated to a separate 256-bit partition BaF because the partition bit arrays are 256-bit long and every partition can host at most 256 link identifiers. Since we allow every node to host pub/sub applications in our model, the limit of 256 accounts not only inter-node links but links towards the hosted applications (i.e., counting a self-link identifier). The maximum partition size is conveniently chosen as 256 because it fits into the source and destination address fields of a IPv6 header.

![Sample topology with three partitions](image)

*Figure 15: Sample topology with three partitions. Poppers correspond to V1, V2 and V3, joining the three partitions*

![Packet header format and the popping operation at V1](image)

*Figure 16: Packet header format and the popping operation at V1 when the packet traverses the path v5 → v1→ v6*

Figures 15 and 16 present the SBA packet format. For our simulation model we also assume that the packet header has two parts: the zBaF that contains the current zone
bit-array used for the intra-partition forwarding, and the cBaF that corresponds to the list of the bit-arrays piggybacked in the packet.

We assume a rather pessimistic approach in bandwidth consumption, therefore, we explore an upper bound. Thus every time the packet traverses a zone, the zone counter at the beginning of the packet decreases, as well as the number of carried zones, thus linearly decreasing the bandwidth overhead as the packet reaches its final destination (with a more elaborated mechanism we could have a logarithmic decrease in bandwidth consumption).

We remark that the Topology Manager is a logically centralised entity similar to an SDN controller, with three main functions: (1) As reported in deliverable D3.1: Initial platform design and set of dissemination strategies, the TM controls the network partitioning implementing several partition management functions for adding nodes, split and join partitions, etc.; (2) TM is in charge of properly assigning identifiers to all links within the network; (3) creating proper routes and coding them into SBAs so that messages can go from the source to the destination. In this analysis, we assume that the function (1) is performed once at the bootstrapping of the network, while operations in the function (2) can be performed anytime during the network activity, whereas function (3) is performed once either for a new multicast tree or after a topological change.

A popper forwarder (or popper) refers to a forwarder sitting at the boundary of partitions (e.g., v1, v2, and v3 in Figure 16). More specifically, a forwarder v is a popper iff where there is at least one edge belonging to a non-common zone among the rest of the edges incident to the popper node. Meanwhile, a forwarder switch (or forwarder) refers to a regular switch with its entire links allocated to the same zone. Forwarder switch is a simple device that only performs basic bit-array based forwarding operations. So, it checks which of its next-hop links are included in the zBaF and then forwards the packets to the corresponding interface. If a packet is intended to a different zone, it must go through a popper that lies at the common node among two or more zones.

Figure 15 illustrates popping operations. The multicast tree (marked as orange arrows) crosses partition borders at two different popping nodes: v1 and v3. When the packet arrives at v1, the popper has to copy the blue bit-array from cBaF to zBaF. After popping, v1 can check to which outgoing blue interfaces the packet should be forwarded as a regular forwarding element. However, the Topology Manager who has assigned the proper Zone ID has already determined the operation at popper v3. Since v3 sits at the border of three partitions, it needs to forward the popped zone properly.

**Edge partitioning**

Given that the cost of the bandwidth, space and processing increases proportionally to the number of zones, the total number of popping in the network needs to be minimised. This performance improvement requires the Topology Manager to select poppers to connect different partitions.
In order to properly formulate the optimisation problem, we first define the required number of popping operations as follows. Let $p_e$ denote the partition that a directed node “e” hosting the publisher belongs to. Let $H_e$ be the set of possible next-hop links in the delivery tree that the packets can traverse departing from $e$. The following equation gives the number of poppings required for each packet departing from “e” (note that the set cardinality tells the number of distinct elements in it).

$$\emptyset_e = \left| \bigcup_{e' \in H_e} \{p_{e'}\} \right| - 1$$

We provide a first approximation to the zoning of a network. In our implementation, we need to satisfy the following conditions for a proper zoning of a network:

- The majority of the traffic should occur within a single partition.
- Each partition should not exceed 256 link identifiers, even counting the link identifier towards the local applications.

By definition, the balanced edge-partitioning problem in the original graph can be naturally solved by applying a balanced vertex partitioning on the corresponding connectivity graph (see [Antikainen] for details). The goal of a proper zoning algorithm, assisted by the Topology Manager, is to group vertices or edges (depending on the strategy) of a graph $G_c = (V_c, E_c)$ into “n” components that satisfy the above stated conditions and minimize the total cost function.

Let $\tau_v$ be the traffic volume on a connectivity graph vertex $v \subset V_c$. Also, let $p_v \subseteq P$ denote the partitions of $v$ according to a cost function, and $N(v) \subseteq P$ to denote the set of partitions to which vertices $v$ share a common link to exchange traffic. The total exchanged traffic, i.e., the cost of partitioning is defined as follows:

$$\text{total}_v = \sum_{v \in V} \tau_v \cdot |N(v)\{p_v\}| \quad (1)$$

From Eq. (1) it is clear that total$_v$, accounting the cost induced by the inter-zone traffic, directly reflect the total popping operations in the network. Thus, the optimal partitioning strategy is obtained by finding a solution that minimizes the total$_v$.

$$\arg\min_{\forall v \in V, p_v} \text{total}_v \quad (2)$$

This optimization problem is well known and it is called graph partitioning while minimizing the communication volume [Hendrickson], and has already been shown to be NP hard. However, there are efficient approximations algorithms that can solve the problem in polynomial time given that the equally sized partitions in slightly relaxed [Andreev].

**Evaluation**

For evaluating the feasibility of the proposed zoning approach we simulated synthetic topologies based on realistic traffic patterns from Guifi.net; furthermore, we used
conventional topology to obtain further insights into the scalability of the zoning strategy. Our aim with these results is to argue about an upper bound in the total number of zones in real conditions considered for the RIFE project.

We use three different kinds of topologies in our evaluations: eight conventional ISPs, one community network, and various synthetic topologies. The ISP backbone topologies are based on the Rocketfuel r0 datasets [Spring]. We dropped the smallest ISP networks having less than 256 links. For the community network, we used the Guifi.net core network in the Catalonia region [Vega]. The synthetic topologies are generated using Barabási–Albert (BA) and Erdos–Rényi (ER) models with various parameters (shown in Table 1). For all aforementioned topologies, we only consider the largest component.

Table 1: Parameters used to create synthetic topologies and partitions

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barabási–Albert G(n,m)</td>
<td>( n \in {500,1000,\ldots,3000,4000,\ldots,8000} ) ( m = 2 )</td>
</tr>
<tr>
<td>Erdos–Rényi G(n,p)</td>
<td>( n \in {500,1000,\ldots,3000,4000,\ldots,8000} ) ( p = (1+\epsilon) \cdot n^{-1} \cdot \ln n, \epsilon = 0.1 )</td>
</tr>
</tbody>
</table>

The realistic trace was obtained with a 30 day monitoring of Guifi network. To generate synthetic traffic, we let every node communicate with any other node with equal probability i.e., we randomly selected a certain number of data sinks for a given source with a uniform distribution. A multicast delivery tree is further constructed by combining the shortest paths between the data source and sinks. Both realistic and synthetic traces contain the information of traffic volume on every directional link. Figure 17 shows the traffic distribution over all the links. Both trace types exhibit similar statistical distributions, which justify our traffic generation method. We assume that the Topology Manager has a priori knowledge about the traffic distributions in the network.

![Figure 17: Comparison of synthetic and realistic traffic patterns. Realistic traffic pattern was obtained with a 30 day monitoring of the Guifi network (Catalonia-region)](image-url)
The vertex partitioning was implemented with the Metis library [Karypis]. We have chosen a popular edge partitioning heuristic called Powergraph [Gonzalez] to establish the mentioned upper bound. The simulation was implemented with Python 2.7 using the Networkx, FNSS, pyMetis, and Scipy libraries. For each configuration, we repeated the experiments 1000 times to obtain statistically valid and representative results.

**Metrics**

In order to assess the impact of the scalability of the multi-zone approach we have calculated the following metrics to evaluate the effectiveness of the SBA scheme.

- The total number of poppers per network.
- The mean number of partitions through which multicast trees traverse. This can be used to calculate further the header overhead produced by the zoning strategy.
- The mean number of poppers through which multicast trees traverse, and the mean number of popping operations for a single multicast packet. These can be used to evaluate the processing overhead produced by poppers when multicasting.

To gain a comprehensive understanding of header overhead, for each topology, we calculate the minimum bit-lengths for LIPSIN IDs that would be required to store a multicast tree while keeping the number of false-positives under a certain threshold. More specifically, we calculate values for function $L_p(s)$, which tells the minimum bit-length for a Bloom filter that can store a multicast tree with “s” sinks in a given topology, while keeping “p” percentage of the multicast trees free from false-positives. Thus, $L_{99\%}(10)$ denotes the length of a LIPSIN ID that, given a topology, can store a multicast tree with 10 sinks while keeping 99% of the multicast trees free from false-positives.

**Results**

The most relevant evaluation results have been compiled into three groups (i.e., unicast with just one sink, multicast with 10 sinks and with 20 sinks) in Table 2 along with some statistics about the topologies. Throughout this section, the whisker bars in the boxplots represent the 5th and 95th percentile values of the measurement while the boxes show the interquartile range.
Table 2: Summary of the evaluation results on both realistic and synthetic topologies using different number of sinks

<table>
<thead>
<tr>
<th>Top</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>H</th>
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<td>1042</td>
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</table>

Legend:

- Top: Rocketfuel Topology Number
- BA: Barabasi synthetic network
- ER: Erdos synthetic network
- C: number of directed links
- D: number of partitions
- E: number of poppers switches
- F: mean number of popping switches on path
- H: mean header overhead
- I: mean header overhead (compressed filter)
- J: L99%{1,10,20} according to the title
- K: L99%{1,10,20} according to the title

Header overhead

We start by analysing the header size for zoning which the header overhead in zoning is the aggregated size of zBaF and cBaF. The size of the zBaF is always 256 bits, while the length of the cBaF varies depending on the number of filters in it, which again depends on the number of partitions a multicast tree traverses through. Notice that cBF is accessed only by relatively fewer nodes (i.e., the popper switches) and therefore, it can be subject to be optimized (e.g., compressed). However, we present an upper bound on the header overheads. Thus, if we let “z” denote the number of zones the delivery tree traverses, the header overhead is 256*(z+1).

Table 2 shows the mean header overheads in all topologies when the multicast tree has 1 (unicast), 10, or 20 sinks. It can be seen that the header overhead (columns H and I) is largely a function of the multicast tree size although the topology also affects it, the effect is relatively moderate. Figure 18 shows that for a relatively few random subscribers (from 10 on) the zoning header size reaches 2048 bits and keeps
constant up to 116 subscribers. The horizontal dashed lines indicate the optimal bit-length for a Bloom filters that can store a multicast tree with “s” sinks while keeping 99% of multicast trees false-positive-free or more specifically, they show the value $L_{99\%}(s)$ for $s \in \{10, 30, 60\}$.

![Figure 18: SBA header overhead (For horizontal lines see the text)](image)

It can be seen from Figure 18 that when a multicast trees grows (i.e., the number of subscriber increases), the size of the zoning header increases accordingly since more partitions are involved in the delivery tree.

**Processing overhead in forwarding**

The key goal of SBA is to allow false-positive-free forwarding while simultaneously minimizing the processing overhead of the packet forwarding. While basic forwarder switches can forward packets with minimal overhead, the same is not true for popper switches. We now present a first overview of the potential processing overhead that is caused by the inter-zone traffic and popping operations. The key metrics used here are (1) the number of popper switches in the network, (2) the number of popper switches on a delivery tree, and (3) the number of popping operations occurring during packet forwarding.

As already discussed, the processing overhead is dependent on how the network is partitioned.

**Scalability of SBA**

We used the Barabasi–Albert (BA) and Erdos–Renyi (ER) models to evaluate how zoning scales as the network grows. The parameters we used for these models are summarized in Table 3.1.

Figure 19 shows the number of popper switches through which a packet traverses as a function of network size. The growth is clearly sublinear. The sublinearity comes mostly from the fact that the network diameter grows sublinearly or the number of partitions...
on a path is limited by the network diameter. This condition guarantees the scalability of zoning in a very natural way. The same sublinear shape can also be seen in the number of popping operations (Figure 20). The number of popping operations (which approximates the processing overhead of the forwarding) grows slightly faster than the number of popper switches. This difference is due to, as the network grows, the probability of a popper switch having adjacent links belonging to more than two partitions grows, and performs a higher number of popping operations. Nevertheless, both the growth in the popping operations and the growth of the header overhead are still sublinear implying good scalability.

Figure 19: Number of popper switches traversed by the delivery tree for 10 subscribers

![Graph showing the number of popper switches traversed by the delivery tree.]

Figure 20: Number of popping operations when delivering to 10 subscribers. Different metrics calculated from a delivery tree with 10 sinks, as a function of the synthetic topology size (number of nodes)

Note: Some error bars are omitted for clarity

Discussion

On the false-positive-free forwarding. The design of a novel zoning strategy, as described in this report, requires that the fixed length partition Bloom filter has at least
as many bits as there are links in the partition. Because of this design choice, the adopted zoning strategy does not suffer from false-positives. It should be noted however, that the SBA like partitioning approach also works with conventional Bloom filter based forwarding system that allows false-positives. However, we believe that the false-positive-free approach described in this report is an alternative approach since probabilistically occurring false-positives derives unnecessary traffic in the network and potentially creates loops [Sarela]. The false-positive-free zoning strategy does not suffer from these problems. There are several existing solutions to solve the problems caused by forwarding anomalies which increases the forwarding complexity. (We refer the reader to Sarela et al. for a more comprehensive description about forwarding anomalies [Sarela]).

**On the addressing.** The zoning strategy consists of an addressing scheme where every link in the network is identified with a unique bit in a bit-string. It may appear counterintuitive in embedding this information into every packet is feasible, however, this naming scheme, nevertheless is the case we have developed. The key insight is that the links in a delivery tree are interrelated. Thus, the network partitioning becomes an effective way to compress (confine and organise) the information embedded into the packets. In a more abstract sense, SBA could potentially be considered as a traffic aware addressing scheme, if there is a lot of traffic between two nodes, then they should be put in a single partition.

**Handling topology changes.** Although Bloom filter forwarding is intended for relatively static networks, no network is immune to occasional topology changes. In general, the zoning strategy handles changes in the network topology as any other Bloom filter forwarding scheme. That is, if one or more links disappear from the network (e.g. due to a switch malfunction), these link identifiers are no longer used when constructing paths. Moreover, when new links are introduced to the network, the Topology Manager simply assigns them new link identifiers (this may require creating an entirely new partition). If this leads to non-optimal partitioning, the network can be repartitioned, as described above, once the topology has remained static for a certain time. Since topology changes can be handled as in other Bloom filter forwarding schemes, we refer the reader to [Zahemsky] for more information about this matter.

### 3.1.2 Backhaul

#### 3.1.2.1 Edge caching

Edge cache refers to the use of cache servers to store content closer to the end users. In addition, it can provide precise positional awareness and agile applications, which can significantly improve user experience. In order to achieve this, and improve over current technology it becomes necessary to consider complementing Edge cache with next generation networking paradigms such as ICN and DTN. In the case of RIFE, Edge caching is applied at the Edge of the fronthaul interfacing to it via the border gateway and to the backhaul via the satellite link. Its main functions allow:
• The storage of content requested by RIFE users, making it possible for other users who are requesting the same content to pick it up locally.

• The prefetching of popular content in order to reduce the traffic load on the backhaul.

When there is a request for downloading content from a website, and once it is downloaded, then the specific content gets cached (stored) to the local Edge caching server, and every subsequent same content request, can be downloaded from that server that is located closer to the user.

The Edge cache server is effectively a proxy cache that works similarly to the browser cache. When there is a request for content from the Edge cache server, an automatic content availability check is conducted in the server. If the content is available and it hasn’t expired, it is delivered to the end user from the local Edge caching server. In the opposite case where the content is not available in the Edge cache, or it has expired from the database, the Edge cache server initiates a new process to request the new content.

One more smart function of the Edge cache in RIFE is that of intelligent prefetching and caching of popular content. This is working through policies applied within the system making the entire network very efficient because it minimizes load speeds. Therefore, the use of Edge cache is an effective way to reduce the traffic load and data congestion in the backbone network. In addition, Edge cache technology is a great technology that allows service availability even in harsh remote environments with no continuous Internet connection or lack of terrestrial infrastructure. Combined with the satellite multicasting technology, the development of Edge cache becomes a powerful tool to address the technical limitations of the past like low speed, high bandwidth dependency, and high backhaul costs.

The Edge cache technology is a very promising technology that can have a positive impact on the business perspective of the RIFE platform and its services. The Edge caching function in RIFE is enriched by push based content fetching solution that is described in this section. Multicasting is also included to further improve performance of a distributed Edge caching architecture within the RIFE platform.

Externally defined web sites are packaged by the multicast server under control of an API (a simple web page control is also available for testing). This server then multicasts the content to a group of multicast receivers. These groups are both configurable and reconfigurable. The multicast receiver then unpacks the websites and uploads the required directory to make it available for the Edge cache server.

The following diagram describes this concept.
The functional RIFE backhaul architecture describes a joint solution by integrating Edge caching solution over satellite link for performance test and validation purposes. The baseline architecture, as shown in Figure 22, will be applicable for the two types of satellite platforms used for testing: emulation testbed (with OpenSAND) and real Satcom link and system.

3.1.2.2 Overview of RIFE push/pull-based satellite Edge caching mechanism

The main work committed in this section is to describe and showcase the Edge caching network over an emulated satellite, i.e., OpenSAND satellite emulator. The mechanism is combined from the following architecture components:

- Policy-based Edge caching software based on Squid Proxy
The simplified system architecture is shown in Figure 23. The mechanism allows a central authority at the backhaul to instruct the multicast terminals in remote area fronthaul to receive content that is being pushed from the ground station to the multicast terminals. The result is that the content is being stored at the terminal local HTTP proxy cache and therefore, proactively offloads the content from the origin servers in the satellite backhaul to the terminal based cache instead. With this, the content caching methods provide content to multicast terminals which offer great potential for improving system performance in terms of offloading the processing/network load from the origin server with transparent user experiences, reducing the response time and latency, while consuming the satellite resources when the system is underutilized (offload during nights).

### 3.1.2.3 Use case description of push/pull-based caching mechanism

One of the use case examples for the push/pull mechanism can improve the access to educational content at remote school sites. Such contents are defined and requested from the school authorities, e.g. classroom notes, and assignments, etc. A central school authority (e.g. head teacher) can define curriculum based material, which is being pushed from the backhaul to the local schools, each equipped with a satellite terminal station, making the content proactively available rather than pulling it on-demand during the courses. Pupils in the schools that lie within the authority that distributed the content are then able to access the content locally through some content caching methods. It is desirable that pupils are able to utilize standard URIs, without any indirections being reflected in the URIs, i.e., the system will take care of utilizing locally cached content and will otherwise (if a local cached copy does not exist) provision the content from the original Internet based source. The mechanism to support this backhaul driven content push use case will be presented in the rest of this document.

In addition, the use case is extended to support the local provisioning of content at specific schools. For this, consider that a teacher at a local school would like to complement the central curriculum material (proactively pushed through the aforementioned provision from the central authority) with research and reading
material that is specific to the school and the teacher’s approach to teaching the curriculum. This additional material might include newspaper articles or multimedia content around an assignment that the curriculum foresees. Such complementary content is specific to particular schools within the district of the central authority. Therefore, we foresee that the teacher defines the complementary material through some web-based tool and a pull-based mechanism to pull the content over the satellite backhaul and stores it locally in a cache, alongside the centrally pushed curriculum material.

3.1.2.4 Mechanism description and testbed scenario setup

The mechanism relies on a combination of 2 types of ECS feeds: pull-based, or push-based.

Based on the system architecture in Figure 23 and Figure 24, this section describes the backhaul mechanism provided via emulated satellite link, the selection and implementation of the appropriate transport service which relies on 5 critical components in the system:

- The Central Authority implements the multicast server and is responsible for the overall control of the service logic. It allows the management of multicast groups and authorizations, sending periods, and rate control, etc. Central Authority may also host an HTTP server.
- The Edge Cache policy management has the ability to schedule the sending of the content requests (and possibly with additional backhaul link information, see the description of the last item).
- A first extension of the QoS/RRM/Scheduler module(s) implemented at the Gateway is able to report usage of resource per spot beams to a trusted controller. This controller can be the RIFE Border GW and/or Edge Cache.
- A second extension of the QoS/RRM/Scheduler module(s) implemented at the Gateway whose goal is to identify servers (IP) and/or content (based on any desired characteristics) for which to apply specific QoS rules. This extension can be managed by a local configuration (management) or can be programmable through an API.
- A control interface between the RIFE Border GW and the RRM backhaul Satcom system. According to the preferred model, messages sent FROM the RRM extension to the RIFE Border GW/Cache should be sent as a multicast signaling (most probably, secured). On the upstream, the interface is used to support the previous API.
In order to get additional material, the Pull based mechanism can be used with HTTP. The local Edge cache can request the content from an external server (Figure 25) or from the Central Authority (Figure 26)
3.1.2.5 Testbed scenario and description of setup

The next scheme illustrates the testbed architecture over the system scenario to emulate. It is composed of:

- A satellite emulator
- A satellite terminal emulator
- A background traffic server sending background stream over the Satcom with low QoS (e.g. iperf TCP)
- A workstation with running IPERF client and ICN application
- A RIFE Border GW
- A RIFE ICN Edge cache implementing distinct caching policies
- An HTTP server
- Multicast server and receiver
A scenario has been developed over a lab platform using RIFE software components and the Satcom emulation testbed, i.e. OpenSAND to implement and demonstrate an innovative pull-based caching mechanism.

In this scenario, the satellite system is expected to provide a multi-service connectivity, or transport service, by means of:

- A default service (pull-mode), with a resource associated to a single satellite terminal that is finally used to serve only end users (located behind the WIFI network in the RIFE case). A unicast satellite connectivity is associated to this resource. This connectivity service shall be used to retrieve content(s) of low popularity, or interest, but that may be need low service delay. It is used typically for individual Web navigation sessions. According to the exact nature of the content, the Edge cache can decide whether to cache or not cache received content.

- A second service (pull-mode) with a resource associated to a given satellite terminal / RIFE Border for contents expect to be of significant popularity or interests, and that probably needs to be cached at the RIFE Edge cache. This category of service possibly involve large content volumes (such as video, etc.) or even interactive applications. A unicast satellite connectivity may be used with this resource to get high QoS. Furthermore, the level of interest can be estimated by the RVS and Edge cache - for example based on the number of end user subscriptions received for the content – the content delivery over the backhaul can be triggered at optimal time of the day/week (off peak periods), such as during nights and/or when the actual load of the backhaul link is low. Such model can be favored by the backhaul satellite operator with affordable costs and/or discount of the capacity volume normally allowed by the Fair Allocation Policy (FAP) during peak hours.

**Figure 27: Overview of software components**
A third service (push mode) is associated to multiple satellite terminals / multiple RIFE Border GWs in order to reach multiple areas. A multicast satellite connectivity can be associated to this resource also with a high QoS. The multicast tree is virtually sourced at one of the terminal and it is done on-demand. For the sake of working with any kind of Satcom topology (star or mesh satellites and systems), the multicast tree is established in two sections:

- **Contribution Section.** From the source satellite terminal to the GW, using on-demand resources. Those resources may be of different natures (from very high priority/ “gold service” towards best effort) based on the desired QoS and costs (but also more operational parameters like, number of satellite terminals, type of service/content, SLAs, etc.) which can be part of the selection process.

- **Broadcast Section.** From the satellite GW to the terminals and using the broadcast satellite capabilities (with or without a dedicated carrier).

### 3.1.2.6 Expected test performance gains

Expected performance gains on different performance metrics are described in this section. This is to show initial validation guidelines towards comprehensive tests which will be performed in the planned validation work throughout the project.

Depending on specific test scenarios, a number of expected performance gain is to be evaluated during the validation of the mechanism. Flow-level KPIs are to be measured for this purpose, as mentioned in section 2, for example in end-to-end latency, average throughput, and packet jitter/error rate.

Apparently, content caching at the fronthaul can improve the response time/latency from the user perspective which can be measured objectively at the fronthaul.

Other measurements can be conducted to show for example, the reduced bandwidth load at backhaul since the content is pre-downloaded to Edge Cache servers where there is less jitter/error rate because of the shorter delivery path.

### 3.1.2.7 Use case: Satellite IP multicasting in educational context (Tanzania Case)

**Introduction**

In deliverable D2.1: Usage Scenarios and Requirements, the use of RIFE for educational purposes was identified as one of the most important user centric use case scenarios. It addresses the societal challenges caused by the lack of Internet access which has significant impact on people’s lives. Therefore, it is perfectly suitable for the evaluation and validation of the RIFE Satellite IP multicasting and push-pull Edge Caching content delivery capabilities because it is driven by the efficient delivery and access control of multimedia content.
In this section, Avanti’s existing experience and expertise in providing educational services is initially described. We then describe the ways that the RIFE platform can be applied in the Education use case, how it addresses the challenges identified, what are the benefits of the satellite IP multicast technology, and how it is compliant to the RIFE requirements is validated. We also focus on the application of this technology in the challenged region of Africa where satellite connectivity could be as well the only vehicle for the delivery of on-line educational content through the RIFE platform.

Background

Avanti’s Applied Technology Team is leading an incubator project in Tanzania called “iKnowledge”4 5 6. This is a project focused on bringing ICT and Satellite Internet Access to schools across 25 regions in Tanzania. The project aims to Connect, Deliver, Train and Sustain schools in Tanzania through the support of its local and international partners. This project uses Multicast Technology. This technology allows information to be delivered to a group of destinations simultaneously, saving network capacity. Furthermore, a satellite solution is the best option to guarantee a resilient broadband service capable of reaching remote schools in Tanzania.

Services provided:

- **Broadband connectivity**: All the sites will be provided with satellite Internet connectivity and multicast content distribution network.

- **Offline instructional content repository**: Schools will be provided a school server maintained by the satellite delivery network, where learning material will be stored, and made accessible to the teachers and the students on all the computers connected to the network.

- **Schools network monitoring and remote maintenance**: Local IT maintainers are provided a simple way of accessing remotely the school servers through the satellite network.

- **Offline instructional content update using multicast technology**: A mechanism for distribution of content using multicast over satellite is provided, reducing the need to visit the school to update the teaching content.

- **Offline instructional video distribution**: The multicast mechanism will allow also the distribution of instructional video material, made available in the school portal. Schools can be grouped by tags defining different distribution based on grades.

The IKnowledge Multicast Content Management System allows the distribution of

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4 [http://www.iknowledge.co.tz/](http://www.iknowledge.co.tz/)
6 [https://www.gov.uk/government/case-studies/iknowledge](https://www.gov.uk/government/case-studies/iknowledge)
offline content, specifically videos and internal software upgrades to groups of schools. The mechanism is controlled by a Back End Portal that packages the content and schedules delivery operations. REST is the main mechanism used for communications and monitoring between the back end and the school servers.

![Content Delivery Network](image)

**Figure 28: Content Delivery Network**

**Content Supported**

1. **Offline learning content update**: Offline content is packaged to be distributed to the schools via multicast and exposed through the school webserver.

2. **Offline Video Content**: Content is uploaded on the back end server and when loaded is transcoded from the original format to the distribution format. The format used for distribution is MPEG DASH. Each video content is always provided with a set of metadata:
   - Video Title
   - Picture Associated (jpg)
   - Description
   - Tags (for positioning on the local web server)

When the video is received by the school server it is added to the local school webserver.
3. **Offline System Upgrade**: Linux sw upgrade are distributed by multicast, and installed using dpkg –i.

4. **Live Video Lecture**: A mechanism to allow teachers to provide remote teaching in audio and video is integrated in the system\fam. The video streaming mechanism used multicast to transport the live video stream, reducing the bandwidth requirements.

**Deployment of RIFE for the Education Use Case**

**Purpose of Education Use Case**

The overall aim of the Education Use Case is to improve (or establish when not available at all) the access to educational, governmental or locally restricted content within the school buildings. Authorized end users (teachers, students and the community) connected to the Internet service can have access to academic restricted material for educational purposes. In this way, the end users can maximize their searching and learning skills while using the modern and user friendly features of the e-learning platforms for their maximum learning benefits. Considering all the above, it is expected that the end users will enhance their learning environment, improve their QOE and their educational level.

**Education Use Case in Africa**

The ICN principal paradigm, does not require an end to end communication between the hosts, and allows the storage of digital content in the network which can be capitalized and become location independent. It is a very useful innovation for the publish/subscribe applications that are extensively used within RIFE. In addition, with ICN, there is a better security model which is a very useful feature that allows more secure transactions in any of its applications.

The Edge Cache is another important technology applied within the RIFE platform that reinforces and maximizes the strengths for the sustainability of the Education Use Case. The ability to transmit content to any location at any time of the day, regardless of the Internet availability, proves to be one of the most successful innovations of the RIFE project, considering the technical limitations in the remote areas of Africa.

Furthermore, the content restriction is an important function that is adapted in the Education Use Case and more specifically in the e-learning platforms. The digital material is developed, managed and distributed in the ICT system infrastructure through the e-platform and is regulated at the local caching server. The subscription of the digital material of the published data refers to the concept of the restricted access. The restriction rules manage the access rights. Both functions are incorporated in the concepts of the content placement and content management, especially when the material is generated by the end users within the school. In such a case, RIFE platform fronthaul technologies provide the capability of the location aware content handling, a very useful feature for the Education Use Case functionality.
The authorized personnel can better generate, manage, distribute and present the restricted material to the school classes or on online portals, autonomously, securely and on time. With these radical technology transformations, it is expected to increase the learning curve among students. On the other hand, teachers are expected to use all the technology features of the RIFE platform, incorporated within the Education Use Case deployment to assist them to teach more efficiently, and prepare, organize and distribute the necessary materials, and finally achieve the best possible teaching outcomes.

**Flow of Content to the end user**

The selected educational material located closest to the local institutions Edge Caching servers, can be managed and be available with the use of the e-platforms such as Coursera. The content is made available by lectures using digital dissemination and multimedia mediums within the institution’s ICT infrastructure.

The local schools can also serve as ‘Hot-Spots’ to provide the content beyond the schools’ end users, namely for local community use. This feature provides the option to the local community to use the Internet services or subscribe, register and use the school’s LAN for the retrieval of digital material for educational purposes.

The published content is always restricted (governed) and can only be available to the local institution’s authorized end users. In the case where teachers can select, generate and disseminate the content to the classes or on the online portal, then RIFE can provide the location aware content management function.

**Typical RIFE configuration for the Education Use Case in Africa**

A typical RIFE deployment configuration for this use case would be in a distributed architecture so that schools in Africa can take advantage of the satellite multicasting features of RIFE. This means that the connected schools would be spread in various locations in Tanzania for example, where each school would be connected to a backhaul satellite network over individual satellite links. In addition, each school’s fronthaul is deployed and functions as a small version of the RIFE platform, leading to a formation of one single configuration of a RIFE cloud platform established by the group of all the joined schools in the area. This configuration is ideal to address the vast distances between communities and schools with satellite multicasting techniques which efficiently addresses the use of bandwidth for the distribution of educational content amongst all parties.

Multicasting can transmit the digital material to a large group of schools, widely spread, simultaneously. This can significantly contribute to the decrease of the cost of distribution of the digital material since the more destinations reached for the material, the more the cost can decrease. In addition to the previous point, there is a potential to increase the negotiation power of the African authorities to bargain for lower prices of the digital material subscriptions from the subscribing organizations for future project needs. This would make more sustainable the entire Education Use Case and RIFE in
Additionally, multicasting combined with Edge caching makes it also possible to deploy the concept of time shifting. More specifically, time shifting refers to planning the transmission of digital material during late night hours (off peak) where there is a considerable less traffic load in the broadband network and usually the broadband service is less expensive since the excess remaining bandwidth can be used at a much lower rate. This content will then be stored in the local Edge cache and become available to users of the RIFE fronthaul the next day, reducing even further the cost of delivery of educational content.

Benefits of the multicasting technology using satellites

Traditional IP networks use end to end connectivity for data transmission. In cases where there is a need for a point to multipoint data transmission, there is tremendous need for increased bandwidth capacity, especially in the streaming services.

On the other hand, and in a more efficient and less costly way, when the satellite IP multicasting technology is applied, there is only one channel dedicated for the data transmission to the multiple defined destinations without the need of any additional bandwidth reserves. That provides a financially sustainable solution for the Education Use Case.

Multicasting is a cost efficient alternative to deploy multimedia content to the schools with environmental and technical restrictions such as in the Africa case, in an affordable way. In the cases of video content in the schools’ educational programs, multicasting in combination with Edge cache can result to a considerable bandwidth reduction, an important aspect for the sustainability of the RIFE and the Education Use Case in particular.

Satellite multicasting mechanism in RIFE

The work done for iKnowledge was for a specific “walled garden community” and focused primarily on the delivery of video content in a centrally manually managed fashion.

For RIFE, we need to adapt this to support standard web page content caching with the possibility to automate the process. This requires the system to acquire web pages and sites, to package this content and the multicast server to send this packaged content via multicast to defined groups of remote sites via the satellite backhaul.

At the remote sites, those multicast receivers that are addressed will receive the packaged content which they will unpack and move the content to the required directories where the content will be made available to end users via a web server. This means that the cached web pages will be available locally from the web server and not require any additional data connections over the satellite backhaul. This will both improve the perceived website load time and reduce the satellite traffic and therefore, costs.
This requires a number of detailed software engineering steps to decouple the multicast software from the video management software; and to add in the capability to unpack the content to multiple different directories on the multicast receivers and to allow the Edge caching server to manage the locally cached web content.

**Network impact**

As an illustration, if 25% of the web page content could be cached locally (primarily the core educational content) across a network of e.g. 200 schools, then the network bandwidth demand would be reduced by almost 25% (24.995%).

This is consistent with observed data where there is a significant amount of traffic which accesses non-core websites either to supplement their education or for personal entertainment. Some filtering is often applied however, significant access is generally found to be beneficial for the pupils.

**Addressing the Education Use Case challenges**

The educational content privacy issues are identified as one of the challenges in the Education Use Case. Specifically, it concerns the content placement, management and governance in e-learning platforms.

Another challenge that has been identified in several developments of the e-learning platforms is the difficulty to encourage the end users to sign up for the digital educational material because the costs for digital material subscriptions are relatively high in relation to the GDP of the general population in an African country. In addition to the above, there is a need to create an online account which needs to be credited with relatively high amounts of money, which makes people negative for obvious reasons.

The technologies in RIFE and specifically satellite multicasting as discussed above have been shown to efficiently reduce the cost of delivery and distribution of e-learning material and platforms. This by itself provides a strong framework for reducing the overall and as a consequence individual cost for this specific educational material to be delivered, managed and used by schools in challenged areas of the world like Africa.
4 EVALUATION FRAMEWORK FOR FRONTHAUL EFFICIENCY

In this section, we develop a network capacity usage model relevant to the RIFE system deployment with an exemplary set-up as shown in Figure 29. The model relies on existing Internet consumption models and content categorization as discussed in [Ref1][Ref2][Ref3][Ref4].

The developed model and its parameters are flexible and can be reconfigured based on the realistic Internet usage data set such as the data set obtained within Guifi.net system.

The objective of this study is to create an evaluation framework to assess and verify estimated efficiency provided by an underlying ICN based distribution technology, particularly the fronthaul efficiency in the event of highly loaded systems.

4.1 System model and assumptions

Figure 29 below shows an example of a distribution network deployment under the supervision of Guifi.net. The local network, which is composed of NAPs attached to the APs and their associated UEs, utilizes ICN to distribute the content within the network of interest. This local network is connected to the Internet backbone to pull and push content based on the user demand, though our primary interest is focused on the local area network distribution.

![Figure 29: Guifi network set-up](image)

In parallel to the current Internet and network capacity usage measurements as demonstrated in [1]-[4], it is assumed that video is the largest content class consumed in the Guifi.net network with X% of the capacity allocated to video transfer with X>50.
Moreover, the video is locally distributed in this set-up leading to local distribution efficiency.

4.2 Traffic evaluation

In the following, we develop a framework of local network capacity usage. In order to identify and tune the key parameters, we initially perform a video catalogue classification based on the realistic usage models devised [Ref1][Ref2][Ref3][Ref4].

- Video Catalogue Classification
  - Long-form content:
    - Entertainment material, film and TV show streaming (Semi-deterministic): Netflix, Hulu type. High correlation of viewing with the initial release of the content.
    - Organized events (Semi-deterministic): Sports organizations type events, e.g. World cup games. Pre-determined dates of the event, with random drawings: e.g. Spain's games have highest popularity in Spain.
    - Event triggered (Random): Periscope type live or archived streaming, possibly due to an extraordinary situation; natural disaster, political uprising, etc...
    - Gaming (Random – clustered usage): Online, peer-to-peer real-time gaming
  - Short-form content:
    - Music videos, short episodes/trailers, e.g. Youtube like content (semi-deterministic)
    - Event-triggered (Random): Periscope type live or archived streaming, possibly due to an extraordinary situation; natural disaster, political uprising, etc...

The catalogue of video classification described above helps in the identification of key parameters in the usage model. Main parameters utilized in the network capacity usage model are:

- Popularity factor and/or number of active requests/views of content $c_i$ as a function of time: $P_{ci}(t)$
- BW requirement of the content, $c_i$ (bits/sec): $W_{ci} >= S_{ci}/L_{ci}$
- Total size of the content, $c_i$ (bytes): $S_{ci}$
- Latency constraint of the content, $c_i$ (sec): $L_{ci}$
- Content initial request time: $T_{init,req}$

Clearly, the delivery of content $c_i$ within its service limits has the minimum data rate requirement:

$$W_{ci} \text{ for } T_{init,req} <= t <= T_{init,req} + L_{ci}$$
4.3 Network capacity usage model

In the following, we provide the analytical model for the network capacity usage.

\[ C_{NET} = \sum_{i=1}^{c} P_{ci}(t) W_{ci} F_T(T_{init.req}, T_{init.req+L_{ci}}) \]

\[ P_{ci}(t) = P_{det,ci}(t) + P_{rand,ci}(t) \]

\[ T_{init.req}(t) = P_{init.req, det,ci}(t) + P_{init.req, rand,ci}(t) \]

where

\[ \text{The In Variable:} \]

\[ \text{Category:} \]

\[ \text{Statistics:} \]

\[ f_{mpci}(t) \]

\[ g_{mpci}(t) \]

\[ f_{mpci}(t): \]

\[ g_{mpci}(t): \]

\[ P_{ci}(t) \]

4.4 Traffic model fitting with the Guifi.net data set

The network traffic model in \( C_{NET} = \sum_{i=1}^{c} P_{ci}(t) W_{ci} F_T(T_{init.req}, T_{init.req+L_{ci}}) \) requires corresponding variables \( P_{ci}(t) \), \( W_{ci} \), \( T_{init.req}(t) \), and \( L_{ci} \) as inputs to develop the suggested network capacity usage framework. Also, as described for the case of \( P_{ci}(t) \), that is the popularity factor of the content \( c_i \), \( 1^{st} \) and \( 2^{nd} \) order statistics of this variable, \( f_{mpci}(t) \), \( g_{mpci}(t) \), respectively, are useful in identifying an average network capacity use case model. Hence, the data set obtained from a network operator, e.g. Guifi.net, shall be processed to extract the following parameters, which are then to be used to obtain the network capacity usage model in \( C_{NET} = \sum_{i=1}^{c} P_{ci}(t) W_{ci} F_T(T_{init.req}, T_{init.req+L_{ci}}) \).

Parameters

- Video content classification transported in the network based on II.\( \overline{r} \) such as \( c_i, i \in \{\text{Long.Hulu.GameofThrones, Long.Netflix.HouseofCards,Long.xxx.xxx, Short.musicvideo.adelle, Short.xxx.xxx,...}\} \)

- In a given duration, e.g. 24 hours/7 days during regular operations, e.g. no World Cup, etc. in action, hit rate/popularity factor of each content class as a function of time. A statistical model of \( P_{ci}(t) \) can be obtained from a larger data set with \( f_{mpci}(t) \), \( g_{mpci}(t) \)
• In a given duration, e.g. 24 hours/7 days during regular operations, e.g. no World Cup, etc. in action, start time of each content class as a function of time. A statistical model of $T_{\text{init}\_req}(t)$ can be obtained from a larger data set with $f_{\text{TNet}}(t)$, $g_{\text{TNet}}(t)$.

• Latency constraints and size of each content class, $L_{ci}$, $S_{ci}$, respectively

• For specific popular events, e.g. World Cup etc., in action, determination of these parameter sets particularly focusing on the duration of the event

Table 3 below shows the key parameters to be extracted from a dataset, e.g. Guifi.net usage over a given period of time. These parameters can be used to tune the usage model described in $C_{\text{NET}} = \sum_{i=1}^{c} P_{ci}(t) W_{ci} F_{T}(T_{\text{init}\_req}, T_{\text{init}\_req+T_{ci}})$.

### Table 3: Capacity usage model parameter set

<table>
<thead>
<tr>
<th>Content Specific</th>
<th>Usage Specific</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W_{ci}$ (BW requirement of the content)</td>
<td>$P_{ci}(t)$ (Number of active requests/views of content)</td>
</tr>
<tr>
<td>$L_{ci}$ (Latency constraint of the content)</td>
<td>$T_{\text{init}_req}$ (Content initial request time)</td>
</tr>
</tbody>
</table>

- $f_{\text{mpc}}(t) = E\{P_{ci}(t)\} \sim \rho_{ci}(t)$
- $g_{\text{mpc}}(t) = \text{Var}\{P_{ci}(t)\} \sim \sigma_{ci}(t)$
- $f_{\text{TNet}}(t) = E\{T_{\text{init}\_req}(t)\} \sim \rho_{T\_init}(t)$
- $g_{\text{TNet}}(t) = \text{Var}\{T_{\text{init}\_req}(t)\} \sim \sigma_{T\_init}(t)$
5 TECHNICAL EVALUATION FROM A SOCIO-ECONOMICAL PERSPECTIVE

5.1 Introduction

This chapter presents a qualitative, technical evaluation of the RIFE technologies from a socio-economic perspective. The obtained results are used as the starting point of the socio-economic validation to be included in deliverable D4.2: Report on Socio-Economic Validation.

The evaluation assumes a socio-economic scenario where an isolated community is underserved with regard to Internet broadband service. Two bottlenecks limit the provision of service: the insufficient backhaul capacity and the low income of community members. The network bottlenecks are the result of low operator investment derived from an uncertain demand.

This section starts defining three configurations: broadband satellite, terrestrial WISP and RIFE. While the first two refer to existing market configurations while the last one describes the RIFE configuration. The RIFE configuration is consolidated via the socio-economic KPIs defined in section 2.2. The RIFE competitive market advantages are identified by comparing the RIFE configuration with the mentioned market configurations. Finally, two value network configurations and commercial solutions are described presenting possible industry architectures and market approaches, respectively.

5.2 Configurations

A configuration defines a set of service conditions and a deployment structure. Three configurations are defined in this section. While the satellite broadband configuration and the terrestrial WISP configuration refer to existing market solutions, the RIFE configuration aims at improving these by using the RIFE technologies. The RIFE configuration will be used as reference in the socio-economic validation to be included in deliverable D4.2: Report on Socio-Economic Validation.

5.2.1 Satellite broadband configuration

5.2.1.1 Service conditions

The current satellite broadband service is typically provided to customers under three conditions. A data volume cap, a bandwidth sharing ratio, and an access policy.

The broadband service offered to the customers is a bundled product sold according to a fixed amount of data (volume), a maximum speed (bandwidth) for a specific billing period (usually on a monthly basis), and in a post-paid manner. If the customer reaches the pre-assigned volume (e.g. 5GB) then the service can be either ceased or the speed to the minimum (e.g. 128kbps) is reduced. To retrieve the initial speed, the customer
will need to purchase additional volume or wait for the new billing period to start. Once additional volume is purchased the speed returns to nominal.

The bandwidth is shared with other end users. The broadband service is based on contended (oversubscribed) bandwidth, meaning a number of users are sharing the same pool of bandwidth (e.g. 50:1).

Fair Access Policy (FAP) ensures that the available satellite broadband network is shared fairly across all customers. For every customer there is a maximum amount of bandwidth/volume that can be used over a fixed time period (e.g. 24hrs or less). Customers that consume more bandwidth/volume than the average user will experience reduced speeds as a result of exceeding their maximum amount ensuring that the majority of the customers will have a better experience as a result of the FAP.

Additional service conditions may apply depending on the service grade (e.g. consumer, professional), region (e.g. Europe, Middle East, East Africa), currency, and the customer minimum required commitment. For example, a relevant additional service condition is the free data usage during the night (e.g. in East Africa between 10pm to 5am UTC).

The following base conditions are used as a starting point of the sensitivity analysis:

- 5 Gbytes data volume cap per billing period
- 1 month billing period subscription
- 15 Mbps maximum download bandwidth (consumer class VSAT terminal)
- 128 kbps reduced download bandwidth
- 2.5 Mbps maximum upload bandwidth
- 50:1 oversubscribed bandwidth ratio
- 1 customer with a total of 5-10 simultaneously connected users using the satellite link (consumer class VSAT terminal)
- Free data usage during night time between 10pm to 5am UTC.

**Configuration deployment structure**

Figure 30 defines the deployment structure including technical components available in the market.
5.2.2 Terrestrial WISP configuration

5.2.2.1 Service conditions

The current terrestrial WISP broadband service is typically provided to customers via flat rate pricing, usage based pricing or block pricing. These pricing structures might be charged either in advance (pre-paid) or at the end of the billing period (post-paid). In addition, upload and download bandwidth are typically limited by a maximum nominal value. Finally, fixed telephony services are usually offered as part of the same bundle with no additional costs.

According to a survey on 21 operators in 16 countries [Sat2015], the flat rate pricing model is the most popular due to lesser administrative overhead and ease of billing. Usage based pricing is also popular with 71% of the operators having partly used this scheme.
Another relevant service condition is the oversubscription rate which highly varies between WISPs. This might lower the customer satisfaction and lead to customer loss in competitive environments. For example, microISPs tend to increase the oversubscription rate to reduce CAPEX, given their impossibility to redistribute losses due to its size. In the case of Guifi.net, oversubscription rate is explicitly defined in the Service Level Agreement defined between ISP and the customer. Moreover, Guifi.net requires ISPs to sign a quality of service agreement in order for them to access the community network.

The following base conditions are used as starting point for the sensitivity analysis based on GUFI.NET ISPs:

- Flat fee pricing structure per billing period
- 3 Mbps maximum download bandwidth
- 3 Mbps maximum upload speed
- A total of N customers
- 1 month billing period subscription

### 5.2.2.2 Configuration deployment structure

Figure 31 defines the deployment structure including technical components available in the market.
5.2.3 RIFE reference configuration

5.2.3.1 Service conditions

The RIFE service conditions are generically defined in deliverable D2.1: Usage Scenarios and Requirements. Pricing structures are preliminarily discussed in section 5.5. The following list defines the key variables to be assessed in the sensitivity analysis.

- Maximum download bandwidth per customer via satellite link
- Maximum upload bandwidth per customer via satellite link
- Maximum download bandwidth per customer via local services
- Maximum upload bandwidth per customer via local services
- Total of N fully connected customers via the ICN fronthaul dissemination strategy
- Total of M disconnected customers via the DTN fronthaul dissemination strategy

5.2.3.2 Configuration deployment structure

Figure 32 defines the deployment structure including the RIFE technologies. Technical components are described in deliverable D3.1: Initial platform design and set of dissemination strategies.
Figure 32: RIFE configuration deployment structure
5.3 RIFE configuration evaluation via socio-economic KPIs

In this subsection, the RIFE reference configuration is qualitatively evaluated via the socio-economic KPIs defined in section 2.2. The objective of the evaluation is to perform a qualitative approach to the sensitive analysis to be included in deliverable D4.2: Report on Socio-Economic Validation. Moreover, this evaluation validates that the RIFE configuration does not introduce additional costs, neither prevents competition or subsidies with respect to the existing market configurations. For simplicity, both satellite broadband and terrestrial WISP configurations are grouped as Non-RIFE configurations.

5.3.1 Network costs KPIs

As justified in Table 4, network costs in the RIFE reference configuration may slightly increase by the increase of nodes and links (e.g. border gateway, access gateway) required to execute the virtual functions (ICN and DTN NAP) as well as the ECS. Nevertheless, transmission costs could be reduced by optimizing the utilization of the satellite link due to the ICN backhaul dissemination strategy and the ECS, and thus, reducing the transit costs.

*Table 4: Evaluation on network cost KPIs*

<table>
<thead>
<tr>
<th>KPI</th>
<th>Non-RIFE configuration</th>
<th>RIFE configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of nodes and links</td>
<td>K BSs</td>
<td>+K access gateways</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+M CPEs (M disconnected customers)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+M access gateways</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+1 border gateway</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+1 ECS</td>
</tr>
<tr>
<td>Characteristics of nodes and links</td>
<td>All devices are commercially available.</td>
<td>Characteristics of nodes will be based on requirements (e.g. KPI 2.2.3.3 Number of supported video streams per router)</td>
</tr>
<tr>
<td>Transmission costs</td>
<td>The satellite operator requires radio spectrum licenses. The terrestrial WISP does not require licenses to operate in the ISM band.</td>
<td>The same mediums are utilized in the three configurations. Therefore no extra licenses might be required. Optimization in the satellite link utilization might reduce transit costs.</td>
</tr>
</tbody>
</table>
5.3.2 Competition KPIs

The compatibility of RIFE technologies with the IP protocol does not necessarily guarantee that competition in the value network remains unchanged compared to Non-RIFE configurations. As discussed in Table 5, the RIFE configuration might exclude actors to participate in the value network if network protocols required by ICN and DTN dissemination strategies are not open. As a result, the interactor competition might be modified. Regarding the internode competition, the introduction of nodes that execute dedicated virtual network functions, such as routing (e.g. DTN NAP and ICN NAP) and caching (e.g. ECS), establishes a new level in the network hierarchy which might also modify the internode competition.

Table 5: Evaluation on competition KPIs

<table>
<thead>
<tr>
<th>KPIs</th>
<th>Non-RIFE configuration</th>
<th>RIFE configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interactor competition</td>
<td>Interfaces between technical components in the non-RIFE configurations are IP. Therefore, actors in the value network can be easily exchanged because IP is an open protocol.</td>
<td>Interfaces between technical components in the RIFE configurations are IP-compatible via gateways except in the BS network. Therefore, actors providing network equipment might be excluded from the value network if RIFE protocols are not open. Therefore, the openness of ICN and DTN protocols might affect actor exchangeability.</td>
</tr>
<tr>
<td>Internode competition</td>
<td>Routing is performed by known and open protocols.</td>
<td>The introduction of routing virtual network functions (DTN, ICN NAPs) and the Edge cache server might modify the internode competition. For example, an actor in control of the Edge cache server could prioritize certain content.</td>
</tr>
<tr>
<td>Interprotocol competition</td>
<td>All commercial protocols are transported over IP.</td>
<td>RIFE protocols are designed to transport IP. Therefore, there is no incompatibility between IP and RIFE protocols.</td>
</tr>
</tbody>
</table>

5.3.3 Subsidy KPIs

The RIFE configuration does not prevent the subsidy of operators or customers as discussed in Table 6. In addition, services that support the accountability of
subsidized actors might improve the fulfilment of subsidizer requirements. Moreover, this would reduce the operational costs relative to stakeholder cooperation.

Table 6: Evaluation of subsidy KPIs

<table>
<thead>
<tr>
<th>KPIs</th>
<th>Impact on subsidies to operators</th>
<th>Impact on subsidies to corporate customers</th>
<th>Impact on subsidies to consumer customers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local and national government subsidy</td>
<td>Governments might require from operators to avoid monopolistic practices (e.g. respect net neutrality). Governments might require accountability about provided services (e.g. customer base increase, delivered QoS).</td>
<td>Governments might require accountability about the utilization of digital services (e.g. number of new e-services, e-services utilization).</td>
<td>Government might support either CPE installation and periodic subscription costs, or support access costs when in coverage.</td>
</tr>
<tr>
<td>Advertiser subsidy</td>
<td>Advertisers might require accountability about the consumed adverts (e.g. advert analytics in the producer side).</td>
<td>Advertisers might require accountability about the consumed adverts (e.g. advert analytics in the corporate side).</td>
<td>Advertisers might require accountability about the consumed adverts (e.g. advert analytics in the consumer side).</td>
</tr>
<tr>
<td>Bank and NGO subsidy</td>
<td>Banks and NGOs might require service accountability from subsidized actors.</td>
<td>Banks and NGOs might require service accountability from subsidized actors.</td>
<td>Banks and NGOs might require service accountability from subsidized actors.</td>
</tr>
<tr>
<td>Volunteer subsidy</td>
<td>Volunteers might require accountability about the benefits delivered to the community (e.g. customer base increase, delivered QoS)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5.3.4 Conclusion

As previously described, the RIFE configuration has a new network architecture level compared to the Non-RIFE configurations. This new level includes the routing functions (e.g. Topology Manager, rendezvous, and forwarder) which are deployed in few selected NAPs. Although centralized routing functions reduce node characteristic requirements, these might also increase the function placing complexity. Moreover, the availability of multiple dissemination strategies such as ICN fronthaul, ICN backhaul and DTN fronthaul enlarges the available options. Although such increase in complexity could affect the technical scalability of the solution, this might not be the case in the medium sized deployment structure of the targeted RIFE reference configuration.

5.4 Competitive market advantages evaluation via KPIs

Table 7 describes the competitive market advantages of the RIFE configuration and determines the KPIs (and other indicators) to evaluate these. Competitive market advantages could be demonstrated by comparing the KPI (and other indicator) values obtained by RIFE technologies with those obtained with non-RIFE technologies.

The evaluation is used in the next section to introduce the benefits of each value network configuration.

*Table 7: Competitive market advantages*

<table>
<thead>
<tr>
<th>Advantage</th>
<th>KPIs / indicators</th>
<th>RIFE Enablers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backhaul capacity optimization</td>
<td>• Link utilization efficiency KPI in the backhaul</td>
<td>• ICN backhaul dissemination strategy</td>
</tr>
<tr>
<td></td>
<td>• Volume of time shifted content to off peak hours</td>
<td>• Edge cache</td>
</tr>
<tr>
<td></td>
<td>• Local content hit rate</td>
<td></td>
</tr>
<tr>
<td>Fronthaul capacity optimization</td>
<td>• Link utilization efficiency KPI in the fronthaul</td>
<td>• ICN fronthaul dissemination strategy</td>
</tr>
<tr>
<td></td>
<td>• Number of coincidental multicast transmissions</td>
<td>• DTN fronthaul dissemination strategy</td>
</tr>
<tr>
<td></td>
<td>• Aggregated multicast throughput</td>
<td>• Edge cache</td>
</tr>
<tr>
<td>Transit cost reduction</td>
<td>• Link utilization efficiency KPI in the backhaul</td>
<td>• ICN backhaul dissemination</td>
</tr>
</tbody>
</table>
5.5 **Initial value network configurations and products**

This subchapter presents two initial value network configurations (VNCs) and products. We define a value network configuration as a set of business actors that provide one or more business roles by the execution of technical components and create value through services [Cas2010].

For this purpose, business actors and roles are described in advance with reference to the business requirements included in deliverable D2.1: Usage Scenarios and Requirements. Finally, two initial commercial solutions are envisioned for a RIFE operator.

5.5.1 **Business actors and roles**

Table 8 describes the major actors in the provision of Internet services, their definition in the context of this chapter, and their main objectives. The traditional actors are...
complemented with actors from alternative network deployments (e.g. community operator) [Sal2016].

Table 9 describes the business roles in the socio-economic scenario as well as technical components. Business roles are discrete set of responsibilities which cannot be subdivided in smaller units of meaningful business.

### Table 8: Actors

<table>
<thead>
<tr>
<th>Actors</th>
<th>Definition</th>
<th>Objectives</th>
</tr>
</thead>
</table>
| Citizen and local business    | Customers aim at maximizing economic surplus by accessing services and content at the most affordable price. Customers develop loyalty to service providers based on satisfaction and quality of service.             | • Connectivity  
• Price affordability                                                      |
| Local community               | Perceived value is shared in the local community. Top-down influence of leaders modify user preferences. Organized community could embrace cooperative management of networks and gain bargaining power. | • Local awareness  
• Local commitment                                                                 |
| Traditional network operators | Wireless Internet Service Provider (WISP) - Regional operator implementing 802.1X technologies (e.g. Airjaldi, India). Satellite operator - The satellite operator routes traffic from the fronthaul to the Internet (e.g. satellite operator such as Avanti PLC). | • To increase number of subscriptions  
• To increase ARPU  
• To low OPEX  
• To low CAPEX                                                                    |
| Community operator            | Local operator which governs the network as a common-pool resource. Community members adopt a volunteer or professional role and can provide services (e.g. Internet gateway, VOIP, infrastructure installation) to other members according to an agreement/license. | • To provide sustainable and fair network services  
• To implement cost-oriented pricing  
• To increase local awareness and acceptance of services                        |
The Content provider serves digital content under particular contractual conditions.

- To increase number of content subscriptions
- To increase hit-rate of content

<table>
<thead>
<tr>
<th>Business roles</th>
<th>Responsibility</th>
<th>Technical components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer</td>
<td>Responsibility to use the available services.</td>
<td>• Video on demand (VOD) application</td>
</tr>
<tr>
<td>Access provision</td>
<td>Responsibility to guarantee network connectivity to the user equipment (UE). It could implement IEEE-based access technologies such as Wi-Fi.</td>
<td>• Base station (BS) • Access gateway</td>
</tr>
<tr>
<td>Gateway provision</td>
<td>Responsibility to aggregate fronthaul traffic and route it towards the Internet or Edge caching server.</td>
<td>• BS gateway • Border gateway • Edge caching server (ECS) • VSAT terminal</td>
</tr>
<tr>
<td>Internet provision</td>
<td>Responsible for routing aggregated traffic to the Internet.</td>
<td>• Gateway earth station (GES) terminal • Internet gateway</td>
</tr>
<tr>
<td>Content provision</td>
<td>Responsibility for contractual conditions required for content distribution.</td>
<td>• Global content</td>
</tr>
</tbody>
</table>

### 5.5.2 Satellite operator driven VNC

In this VNC, a satellite operator assumes the following business roles: Internet provision, Gateway provision and the Access provision as shown in Figure 33. As a result, the satellite operator operates the complete solution and offers Internet service directly to customers. Due to the large coverage across multiple continents, the satellite operator would most likely define global and static service plans to customers.

#### 5.5.2.1 Benefits

The satellite operator might benefit from all competitive market advantages defined in section 5.4 because it operates all the network infrastructure in a centralized way.
5.5.2.2 Costs

The satellite operator is responsible for installing, maintaining and operating the complete solution. The satellite operator benefits from scale advantage when negotiating with providers (e.g. bargaining power with equipment providers). The static nature of the global service plans might limit its ability to attract subsidies.

5.5.2.3 Revenue model

The satellite operator might collect revenues not only via Internet subscriptions from customers, but also from content providers interested in locating content in the ECS. This way, the satellite operator might sign caching contracts that guarantee the content QoS delivery in the Access provision as shown in Figure 33.

5.5.2.4 Internet subscription pricing

The satellite operator might offer several global, static service plans similarly to the service conditions defined in section 5.2. A possible innovation would be, for example, to create a different volume cap for local services.

![Diagram: Satellite operator driven VNC](image)

**Figure 33: Satellite operator driven VNC**

5.5.3 Commercial Solution 1: Satellite Local Area Network (SATLAN)

This solution elaborates a possible RIFE commercial solution taking the business actors and roles defined in the Satellite operator driven VNC.

5.5.3.1 Value Proposition

The SATLAN solution will enable satellite operators to provide an improved, reliable Internet service to organizations that require medium-size wireless LAN coverage in an
easily deployable manner. This product will promote the sustainable development of underserved regions not only connecting organizations to global services, but also establishing organization’s critical services (e.g. project management or collaborative tools) in the local network.

5.5.3.2 Target Customers

The target customers mainly belong to the corporate segment which are located in underserved areas and require a reliable and easy deployable Internet service. For example, government offices with several buildings in the same compound, hospitals, and hotels, etc.

5.5.3.3 Service Use Cases

The SATLAN main services use cases are e-health, e-education and e-tourism. These are described in deliverable D2.1: Usage Scenarios and Requirements and will be demonstrated in the RIFE testbed in Catalonia.

The SATLAN solution will enable both educational and healthcare services to access already existing global e-learning/e-health services as well as to deploy and use local services. Satellite operators would be able to serve a larger number of education and health facilities in a more scalable manner.

The SATLAN solution can substantially improve the Internet service of businesses in the accommodation services sector as well as tour operators.

5.5.3.4 Market introduction

The solution might be introduced to the market via:

- Direct Offer: The satellite network operator will be responsible for marketing, selling, supporting the RIFE platform in each country or area and will receive return through revenue share.
- Wholesale / White Label: The RIFE platform, equipment and managed service are supplied wholesale. RIFE services are offered directly by a local distributor and may be rebranded.

The business models that will be developed further in deliverable D4.2: Report on Socio- Economic Validation will show how the satellite operator, the distributors can profitably deliver the RIFE platform based on expected costs and sales.

5.5.4 Cooperatively driven VNC

In this VNC, a satellite operator cooperates with a terrestrial operator. Therefore, the satellite operator only assumes the Internet provision business role. Consequently, the terrestrial operator assumes the following business roles: Gateway provision, and Access provision. It is not the objective of the VNC to identify the business nature of the operator (e.g. for-profit WISP, a non-profit community operator), but the implied benefits and costs of the industry architecture. In any case, the satellite operator
provides backhaul connectivity via a transit contract as displayed in Figure 34. The terrestrial operator is typically smaller in size than the satellite operator and therefore, it is able to provide flexible service conditions to customers.

5.5.4.1 Benefits

Regarding the market competitive advantages, the terrestrial operator might benefit at least from fronthaul capacity utilization increase and fronthaul coverage increase. The terrestrial operator might also benefit from backhaul capacity increase, transit cost reduction, and local services improvement depending on the transit contract conditions with the satellite operator.

5.5.4.2 Costs

The terrestrial operator is responsible for installing, maintaining and operating all the network infrastructure except for the satellite link. Due to the flexible service conditions, the terrestrial operator might benefit from additional cost reduction as the result of subsidies (e.g. a non-profit WISP might benefit from community volunteer work) as described earlier.

5.5.4.3 Revenue model

The satellite operator collects revenues from the terrestrial operator via transit contract. The terrestrial operator collects revenues via Internet subscriptions from customers. The terrestrial operator’s ability to reach caching contracts might be limited by its small customer base which does not guarantee a minimum content hit rate. Moreover, the terrestrial operator faces problems to cache content because of the end to end encryption of communications.

5.5.4.4 Internet subscription pricing

The terrestrial operator could offer two pricing structures to differentiate the access to the ECS content from the access to the Internet content. First, a block pricing structure could be charged to access the Internet content via the highly utilized satellite link. Secondly, a more affordable tariff or different structure (e.g. flat-fee pricing) could be charged to access the ECS content via the Access network, the utilization of which, might not be as high. Under certain circumstances, the customer might benefit from direct subsidies (e.g. customers are subsidized by an NGO or an advertiser) as described previously.
5.5.5 Commercial Solution 2: TurboWISP

This solution elaborates a possible RIFE commercial solution taking the business actors and roles defined in the Cooperatively driven VNC.

5.5.5.1 Value Proposition

The TurboWISP solution will enable terrestrial operators not only to provide improved Internet service, but also reliable local services. The TurboWISP solution will enable terrestrial operators to optimize the backhaul link utilization, to cache popular content and to improve the efficiency of the terrestrial wireless network.

5.5.5.2 Target Customers

The target customers of the TurboWISP solution are terrestrial operators in underserved areas that assume costly backhaul transit costs. The TurboWISP solution fits well to those terrestrial operators aiming at the operation of local services and expansion of the wireless coverage. For example, target customers might be for profit WISPs, and community networks, etc.

5.5.5.3 Service Use Cases

Service Use Cases that fall under the TurboWISP solution are the Rural Africa and Western Europe Use Cases as these have been identified in the Deployment centric Use Cases of deliverable D2.1: Usage Scenarios and Requirements. These two Service Use Cases address different deployment objectives however, both of them can be supported within this solution.
The Rural Africa Use Case is aimed at providing broadband Internet access in rural areas (usually in the Africa continent) that are poorly developed or where telecommunication networks are inexistent. Through the RIFE platform emphasis will be given to the reduction of the overall operational costs and more explicitly to the reduction of the backhaul capacity with the ultimate aim of providing less expensive backhaul solutions.

On the other hand, the Western World Use Case is aimed at reduction of the fronthaul capacity and to the implicit content placement for the end users since these areas already have existing high capacity backhaul and fronthaul infrastructure. The usage of the RIFE platform will focus in this use case on how to make the Internet experience more tactile for users facing a poor broadband service and to further optimise the operational expenses for operators across their entire infrastructure.

5.5.5.4 Market introduction

The solution might be introduced to the market via:

- Wholesale / White Label: The RIFE platform, equipment and managed service are supplied wholesale. RIFE services are offered directly by a local distributor and may be rebranded.

The business model that will be developed further in the deliverable D4.2: Report on Socio-Economic Validation will show that the terrestrial operator or a 3rd party service provider can profitably deliver the RIFE platform based on expected costs and sales.
6 CONCLUSION

This document described the RIFE technical and socio-economic Key Performance Indicator (KPI) metrics as well as the technical and socio-economic evaluation scenarios. The document showcased the results from the intermediate technology validation with focus on (1) the fronthaul ICN dissemination strategy using both the simulation and emulation platform, (2) the push/pull-based satellite Edge caching mechanism using the emulation platform, and (3) the RIFE reference configuration as an initial market approach.
7 REFERENCES


[Click] The click modular router project. http://www.read.cs.ucla.edu/click/


