Decoupling Resource Ownership From Service Provisioning to Enable Ephemeral Converged Networks (ECNs)

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***Abstract*—The evolution of wireless and optical networks will involve not only the adoption of new technologies but also massive changes in how network resources are owned and managed. In this paper, we describe current trends in decoupling resource ownership from service provisioning, which can be observed in both wireless and optical networks. Moreover, we present our vision of how these trends will evolve towards virtualized on-demand service-oriented networks that can be created by combining shared network resources. This type of network lasts for the time connectivity, to deliver services, is needed, then releases the resources when and where they are not no longer needed.**

***Keywords*—converged networks, optical/wireless, virtualized networks, resource sharing, network intelligence, resource allocation, dynamic composition**

I. Introduction

Over the next years, the number of wireless device connections is set to increase dramatically, with predictions that fifty billion devices will be connected to the internet by 2020 [1]. The typical user profile is shifting from fixed to mobile, and data consumption patterns are changing dramatically, towards video, interactive gaming, machine-to-machine communications, etc. To cope with this new environment, we argue that network operators must re-think their current business models, their infrastructure ownership, and their service management, evolving from owning all the resources (infrastructure, spectrum licenses, etc.) to sharing resources, and decoupling resource ownership from service provisioning. In the wireless arena, we believe that 5G networks will be characterized not only by the adoption of new technologies [such as massive Multiple-Input Multiple-Output (MIMO) and new waveforms] but also by a dramatic change in how network resources are owned and managed. Virtualization will then pave the way for on-line service-driven networks.

Today, there are multiple applications and services which directly target the end-user and divert revenue and value away from the network operator. There are coverage demands that fly in the face of economics. There are ever-increasing needs to bring fibre everywhere to deliver higher data rates and more backhaul. There is the need for operators to acquire new spectrum, roll out new networks, upgrade technology, and reduce costs. There is the wider economic background - one of world-wide recession, shrinking investments, and foreboding prophecies of there being only room for a small number of equipment vendors and a small number of network operators on the world stage.

In this context, we believe that ownership of physical infrastructure should be entirely separate from the offering of services to the end-user, moving towards a virtual operator business model where network service providers may not own the underlying physical network infrastructure [2].

The underlying philosophy of the optical/wireless converged end-to-end architecture we propose is one that embraces sharing of a collection of disparate resources [content, applications, aggregators and filters, devices, spectrum, fixed links, radio access network equipment, switches and routers, storage capabilities, processing power, space, energy sources, ideas, intellectual property] that can be combined in different ways to offer services as and when they are needed to the end-user, creating an Ephemeral Converged Network (ECN). Temporally, ECNs exist only when they are needed, being created and released on the fly; spatially, an ECN provisions resources throughout a region to locally serve the needs of the connectivity requester.

II. Current infrastructure and service ownership trends

In this section, we describe common network ownership models in today's telecommunications market. There are indicators that current ownership models are currently undergoing major changes, for both access and core network operators, in the wireless and optical domains.

A. Wireless domain

Regarding mobile communications within licensed spectrum, the last decade has witnessed the entry of Mobile Virtual Network Operators (MVNOs) into the telecommunication market. MVNOs offer mobile services to end-users without owning infrastructure or holding spectrum licenses, working in conjunction with Mobile Network Operators (MNOs). The latter hold licences to operate in licensed spectrum and own Radio Access Network (RAN) infrastructure and management-service systems.

To provide mobile services, several elements are required in the infrastructure and the service value chain (e.g., RAN infrastructure, core switching elements, billing and accounting).

TABLE I: Resource and Services ownership for the licensed frequency based operators

Domain	Infrastructure			Service Management					
Type	Spectrum	RAN	Core	Value Added Services	Service Platform	SIM Card	Billing	Branding	Sales & Distribution
MNO	△	△	△	△	△	△	△	△	△
Full MVNO			△	△	△	△	△	△	△
Hybrid MVNO				◯	◯	△	△	△	△
Light MVNO				◯	◯	◯	◯	△	△
Brand MVNO								△	△

△ Ownership. ◯ May or may not own it.

Depending on the type of MVNO, it can own some or none of those elements, or, alternatively, become just a reseller of the services offered by the host MNO. Nevertheless, the co-existence of both MVNO and MNO allows the development of new options in the telecommunication market that benefit users and specialized segments of the market. This also increases competition in the mobile services market, drawing down prices. We summarize the different types of MVNOs in Table I. The infrastructure ownership is decoupled from the service provisioning, allowing MVNOs to emerge [3].

With the success of the wireless technologies that rely on unlicensed spectrum, e.g., Wi-Fi, wireless networks are being deployed not only by traditional MNOs, but also by new actors, such as specialized global commercial Wi-Fi operators (e.g., Boingo), municipalities, business, and end-users. Table II presents the role of these actors. We observe the trend of decoupling resource ownership from service provisioning in unlicensed spectrum as well. For instance, the Municipal Wireless Networks (MWNs) are deployed by the local government in urban areas; however, in some cases the management and exploitation of the infrastructure is done by a third party [4]. Peer-granted access for residential user of wireless networks, such as the global Wi-Fi network managed by Fon[1], provides another example of resource sharing is unlicensed spectrum.

B. Optical domain

Ownership of fixed access and core networks has followed different evolution paths since the privatization of national telecommunication networks. Core networks have attracted different private investors. In particular, those companies that already owned long-distance infrastructure, such as electricity, rail, water and other utilities, have taken advantage of their existing ducts to lay long-distance fibre. The reason is that the network core aggregates services from a large number of users, thus every optical link can be quite profitable.

The access infrastructure has instead remained practically unchanged, until the recent deployment of fiber-to-the-Home (FTTH). Contrarily to the core, the cost per user of access links is very high, and their long time to profit makes investments more difficult to justify.

[1] http://www.fon.com

TABLE II: Resource and Services ownership for the unlicensed frequency based operators

Domain	Infrastructure			Service Management		
Type	Spectrum	RAN	Core	Value Added Services	Service Platform	Billing
MNO		△	△	△	△	△
Wi-Fi operators		△	△	△	△	△
MWN		△	△	◯	◯	◯
Commercial User		△		◯	◯	◯
Residential User		△				

△ Ownership. ◯ May or may not own it.

As a result, the only network access available was for a long time copper access provided by incumbent operators, and telecommunication regulators had to resort to a regulatory process known as Local Loop Unbundling (LLU) to open the access market to other operators [5]. As the old copper network has become the bottleneck for new bandwidth-hungry services and applications, a number of operators have started to provide fibre access services.

Different regulatory views on the application of LLU rules to fibre have led to different deployment scenarios around the world [6]. In places like the US, Japan and Korea, where the incumbents have encountered a favourable regulatory environment, they have provided extensive FTTH installation. In most European countries, instead, operators with a dominant market presence (all incumbents fall into this class), are forced by EU regulation to apply unbundling also to the fibre network. Thus they are required to give access to their newly deployed fibre to any other provider, using pricing models imposed by their national regulators. For this reason many European incumbents have so far deployed little or no fibre. Smaller businesses, instead, which do not have significant market presence and are not subject to unbundling regulations, have often provided local FTTH installations, leading to a much more fragmented and competitive fibre broadband market.

Most fibre to the premises installations to date use a technology called Passive Optical Network (PON), which employs passive optical splitter elements to reduce the average cost per user, by sharing optical fibre and electronic termination. Although the ownership scenario has become quite complex, the FTTH Council Europe has classified access services into three categories, as shown in Figure 1: i) passive infrastructure: ducts, fibre, splitters and splicing housings; ii) active infrastructure: optical terminations at the user [Optical Network Unit (ONU)] and network [Optical Line Terminal (OLT)] sides, reach extender and access switching equipment; and iii) retail services: services being offered to end-users, such as telephony, TV, broadband.

The FTTH Council has envisaged four different scenarios in terms of access service ownership, summarized in Figure 2.

- **Vertical integration.** This is typical of incumbent op-

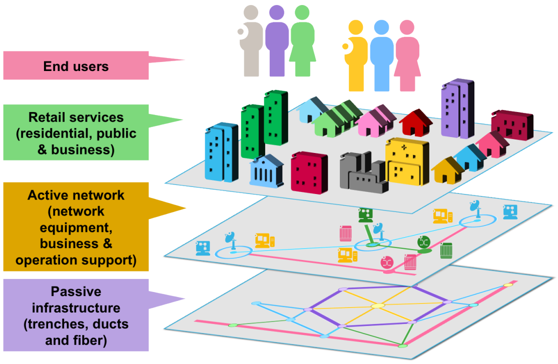

Fig. 1: FTTH network layers (based on [7])

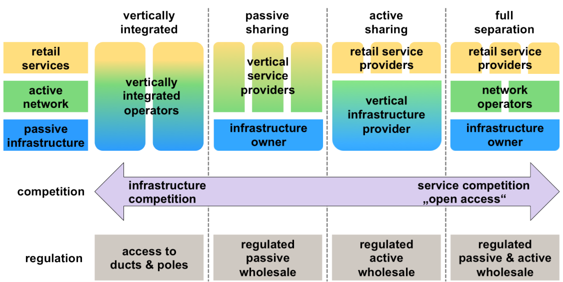

Fig. 2: FTTH Ownership Models (based on [7])

erators that own all three service categories. Competition starts from the infrastructure level, as no resource sharing is mandatory. The operator is required to build its own network in order to enter the market, while the only shared infrastructure might be ducts or poles.

- **Passive sharing.** In this case the ownership model is split between one passive infrastructure operator (a regulated entity which is required to guarantee fair access to other providers) and multiple vertical service providers that both own access infrastructure and provide retail services. This solution increases the competition, as it allows a new entrant to lease fibre infrastructure, which is by far the most expensive part of an access network, at a fair price. However, new entrants are still required to be both network operators and service providers, which is still a barrier for small new entrants. Typical passive infrastructure operators include municipalities (e.g., Stokab in Stockholm) and larger-scale providers (e.g., Reggefibre in the Netherlands) [8].
- **Active sharing.** Ownership is divided among a vertical infrastructure provider, owning both passive and active infrastructure, and a multitude of retail service providers. This solution moves the competition towards the service, as now retail service providers are not required to own any infrastructure but can instead operate their services on top of the infrastructure provider, thus incurring lower market entrance barriers. The infrastructure provider becomes a regulated active wholesale provider.
- **Full separation.** In full separation, we have different players for the three different categories, leading to a full open access network, where multiple active network operators can share the same fibre infrastructure, and multiple retail service providers can select any of the available active operators. This scenario introduces a new network player, the active operator, which only owns active infrastructure: it leases fibre from the passive infrastructure provider and provides wholesale services to the service providers.

III. Shifting the Paradigm

We argue that an architecture for next generation networks involves: i) greater focus on the sharing of resources; and ii) increased dynamism in the operation of the networks. The main idea of the architecture is summarized in Figure 3. The focus on sharing arises from scarcity of network resources (in particular in wireless networks) and a desire to more effectively use existing resources, and is driven by capacity requirements and cost factors. Increased dynamism follows from sharing of resources, insofar as its motivation is to be able to direct resources to where and when they are needed. Increased dynamism is also driven by the fact that networks are increasingly complex, heterogeneous, and ever more unsuited to traditional control and intervention.

Our end-to-end architecture rests on the sharing of resources, e.g., infrastructure, spectrum/bandwidth, storage, or processing power where appropriate, and embraces dynamic and reconfigurable elements as an evolvable path to future configurations. The architecture does not include specific backhaul elements - instead, we deliver services to end-users through ensuring that the resources needed for the particular service are made available at the point of need. We adopt an approach of *no preferential Point of Attachment (PoA)* to the optical network, which allows a Basestation (BS), a data centre, or a household broadband connection to hang from any part of the optical network.

The sharing of infrastructure means different things across the wireless and optical networks. We consider a pool of private, public, or crowdsourced wireless and optical resources, including advanced passive optical network elements. The dynamics in the network vary on the optical and wireless sides in terms of time scale and due to the different capabilities and limitations of wireless and fibre media. Irrespective of these differences, there is an acknowledgement across the wireless/optical domain of the fact that the operating conditions, user demands, and resource availability are constantly changing.

Our ECN architecture is built around the concept of Networks without Borders (NwoB) [9] in general, and Ephemeral Wireless Networks (EWN)[2] in particular, which envisions a pool of resources from which a virtual wireless network can be architected and deployed. Flexibility and technology neutrality are key goals of this architecture, mirroring the Internet, where user services are independent of the underlying network control mechanisms or infrastructure. As these flexible networks are shaped out of resources deployed by multiple infrastructure providers, NwoB and EWN fundamentally re-imagine the

[2] http://www.slideshare.net/JohannMMarquezBarja/ephemeral-wireless-networks

traditional structure of commercial mobile networks, enabling new models of network ownership and service provisioning.

Our wireless architecture virtualizes many of the complex processes and functions that underlay current mobile networks, from network management to mobility management and authentication. These processes and functions can be turned into services, which can be traded among different parties of the newly formed telecommunications value chain. As a part of this vision, the physical radio access infrastructure becomes primarily a transport for bits (packets), or otherwise an interconnection point to the cloud of services.

We believe that this approach will lower barriers to entry for new players in the wireless market, at all levels, from infrastructure provisioning to mobile application services. These networks will continue to evolve towards greater heterogeneity of access technologies and consist of a hybrid of macro- and small cells, the latter an important component of any solution to increase overall wireless network capacity. This, in turn, requires larger and deeper penetration of the optical network.

On the optical side, we are developing extensions to the Fiber-to-the-user-premises (FTTP) architecture that encompass the use of Long-Reach PON technology. LR-PON derives from the hybrid seamless TDM/WDM-PON solution, where a power split PON is upgraded to support many wavelength channels. In addition, by placing an optical amplifier at the local exchange, the optical reach can be extended to over 100 km, bypassing any intermediate electronic data processing, while increasing the number of users to about to 1,000. The result is a much cleaner architecture, where local exchange nodes can be bypassed, and user signals terminate directly at core nodes. The number of active nodes in the network is reduced, leading to a considerable reduction of electronic processing equipment, thus reducing both CAPital EXpenditures (CAPEX) and OPerational EXpenditures (OPEX), in the medium to long term. One of the main advantages of LR-PON is that it has the potential to reduce deployment cost both in urban and rural areas, laying the basis for a highly ubiquitous high speed access network [10].

Once FTTP achieves high penetration in a certain area, it makes sense to use it for as many services as possible. Since the main cost of deploying a fibre network is laying the fibre, it becomes much more cost effective for a wireless operator to interconnect the mobile network infrastructure (e.g., macro and micro cells) to an existing PON rather than deploying an additional proprietary point-to-point (p2p) fibre backhaul.

In relation to the ownership models presented in Figure 2, this can be achieved by adopting architectural options that enable competition at the service level, for example following the "open access" model, which can be achieved both with an active sharing and a full separation model. Both models can, in fact, achieve the primary objective of moving competition from the physical layer (i.e. raw bit per second peak broadband speed) to the service layer. This would enable highly dynamic management of network capacity, where service providers might automatically be given access to the bandwidth required to deliver a particular service that their customers request.

To enable such an integrated architecture, we propose new network entities, as shown in Figure 3. In this model, the end-user subscribes to one or more services offered by the service provider. These services will be bundled with connectivity access, which will be provided and controlled by a Broker, which interacts with one or more infrastructure/network providers to determine the appropriate set of resources in the network that will yield the desired coverage and capacity for the network, while best meeting the needs of the end-user and the service. The broker operates on the virtualized shared resources owned by different infrastructure providers. These resources may be of an heterogeneous nature and ownership, including assets in the current mobile and wireless networks, household access points, cloud-based services, frequency spectrum, as well as passive optical networks. Each role described above may be played by one or more entities in the telecommunication services market, and a single entity may function with more than one role.

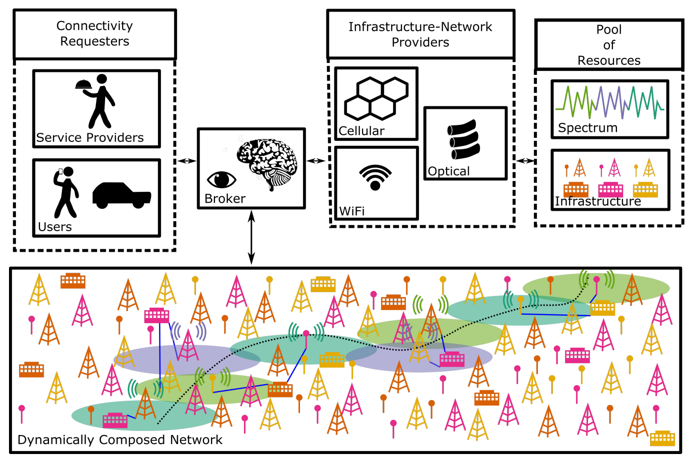

Fig. 3: ECN converged architecture

In summary, we envision the future single unified 5G end-to-end network as a virtualized service-oriented converged network. This will allow end-users to connect with flexible virtual on-demand networks that fulfill their requirements, without the need for an exclusive subscription to the infrastructure owner. This virtual network will result from the aggregation of different resources from diverse networks (e.g., devices, infrastructure, services). This vision involves the cooperation and the sharing of resources not only among providers but also among users. To achieve this goal, all the players engaged in the telecommunication process must collaborate to dynamically share network resources and build the virtual network, thus disrupting the current network and market models.

IV. ECN AS A SOLUTION

We identify three distinct scenarios in which our ECN architecture uniquely facilitates the development of future networks.

a) Use Case 1 The impact of broadband wireless on optical infrastructure: Broadband wireless brings unprecedented requirements for the wireless access connection (e.g. cell throughput capacities of 10-100 Gb/s and peak access rates per user of up to 1 Gb/s). At the same time, a dramatic paradigm shift is observed in internet usage with multimedia traffic, and especially video, occupying the largest share of the available capacity (e.g. to support 4K and 3D video services). While optical networks are certainly well suited to provide high data rates, the construction of an optical network dedicated to the service of mobile broadband is an economically infeasible option. Rather, both optical and wireless resources must be dynamically shared across several applications to balance increasing traffic demands against stagnant revenue growth.

b) Use Case 2 The design of optical backhaul for next-generation wireless: Fundamentally future network scenarios precipitate new demands on the optical backhaul both in terms of capacity and latency. Simultaneously, economic and technical realities demand a convergence of access and metro within optical networks [10]. Handling the combined impact of wireless demands on backhaul and a re-imagining of optical networks architectures requires a joint consideration of these realms. As novel wireless scenarios such as densified networks and Cloud Radio Access Network (C-RAN) arise, the optical backhaul must be flexibly adapted to meet new challenges. While Software Defined Network (SDN) approaches offer some useful functionality in this regard, a joint consideration of wireless and optical networks is necessary to match wireless networking approaches to appropriate techniques for optical backhaul.

c) Use Case 3 The interplay between bursty, low data rate wireless and optical network architectures: The concept of the Internet of Things (IoT) invokes a very large number of connected devices, typically operating in a potentially bursty, but ultimately low data rate manner. A major challenge of this scenario is the need to support a huge number of inexpensive devices. Furthermore, the arrangement and utilization of these devices ranges from straight forward to the exceedingly complex. Moreover, traffic generated and carried in IoT networks is the result of natural or human phenomena, which are unlikely to follow any convenient schedule. Support of such ubiquity of communication requires an aggregation between various wireless services and optical networking. Note that this must be accomplished in a manner that is able to handle potentially frequent communication between network and device in a low overhead manner. Specifically, handling these transactions requires the network to support a truly connectionless mode of operation, where devices can simply wake up and send a short burst of data.

The recently funded project FUTEBOL (Federated Union of Telecommunications Research Facilities for an EU-Brazil Open Laboratory)[3] is developing and deploying research infrastructure in the optical and wireless domains, and an associated control framework for experimentation that will enable experimental investigations of the three scenarios outlined above.

V. Conclusions

Current solutions to provide end-to-end connectivity are struggling to scale in order to meet the ever-increasing demand, and are constrained by the current revenue model adopted by network operators. The end-to-end architectural vision, called Ephemeral Converged Networks, proposed in this paper shifts the current paradigm towards decoupling resource ownership from service provisioning, meaning that the network can be virtually and dynamically configured based on a wide range of available resources such as spectrum, wireless and optical infrastructure, authentication, and network accounting.

[3]http://www.ict-futebol.eu

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