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Abstract

Mobile and Wi-Fi communications have become a part of everyday life in the R&E community. This paper addresses the network architectures that enable the improvement of the quality of wireless services provided to clients within universities, NRENs and GÉANT.

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Executive Summary

This white paper summarises the research directions identified in JRA1 Task3. Throughout the document, the research group has used the model of an R&E networking organization. Section 2 of the document analyses the current situation with high-speed Wi-Fi and mobile networking. It emphasizes the growth in the number of devices and traffic as a factor in planning the future capacities of NRENs' and GÉANT's core and backbone networks. The study also points out the complexity of implementing Wi-Fi in a planned manner within R&E organizations. It also considers the fact that Wi-Fi alone is not enough to fulfil the requirements of the R&E community. A number of proposed network architecture solutions to address the identified issues are presented in Section 3. The research group considers high speed Wi-Fi and mobile to be access technologies, and that most of the new network architectures will be implemented in the access layer. The requirements for backhaul through R&E core and backbone networks are within the range of currently implemented network architectures. NREN and campus networks will have to implement new network architectures and protocols to realise the requirement for seamless connectivity. Finally, the document provides an outline of the possible scenarios for integration between Wi-Fi and mobile network architectures, and of a Wi-Fi-as-a-service architecture to provide Wi-Fi coverage for small R&E institutions.

1 Introduction and context

Mobile and Wi-Fi (wireless) data communications have become a part of everyday life. The industry proposal for Horizon 2020 network architecture [Horizon2020] considers the possibility that one trillion devices will be connected in Europe alone. There is no evidence that the pool of connected devices has reached a high saturation phase and that growth has been slowing down. The volume of data transferred over Wi-Fi and mobile networks is increasing. This imposes a requirement for network capacity at all layers from access to core.

The research community sees the pervasiveness of mobile data connections as an enabler of new learning experiences. This has led to the creation of mobile learning environments – a concept that is over a decade old [Anderson, T.]. More advanced learning environments are currently under discussion within the R&E community [Wong, L. H.]. Mobile learning involves much more than the use of devices. It presents unique attributes compared to conventional e-learning: it is personal, portable, collaborative, interactive, contextual and situated. Mobile learning puts high requirements on both learning content and on the ICT infrastructure. The deployment of these mobile learning environments has three major implications for networking:

1. **Ubiquitous access to content.** This implies that users require sufficient connectivity for their learning activities both on and off their institutions' premises. It requires that both Wi-Fi and mobile (3GPP LTE, LTE-A) means of communications be used to deliver an integrated service.
2. **Access to network resources.** Easy access to the network from any device makes mobile learning portable and personal and accessible from any device. This requires the integration of authentication solutions that are used both in the mobile world (SIM cards) and education environments (combination of user name and passwords and certificates).
3. **Widening of the user base**. Mobile learning environment implementations, such as Brand's & Kinash's pilot test of the iPad [Brand, J., Kinash, S.], target primary and high schools rather than universities and research centres. This implies that sufficient Wi-Fi and mobile network connectivity has to be ensured throughout all learning environments. Small organizations such as schools and vocational training centres are less likely to have the resources to deploy their own infrastructure and will rely on commercial operators unless the R&E community can respond to these requirements.

The research and education community has an established precedent in the provision of Wi-Fi access in the implementation of its successful trust-based federation for roaming, eduroam. This is based on the authentication of user credentials regardless of the device the user is logged on. Mobile networks, on the other hand, have been evolving in a different direction: the mobile network authenticates the device (SIM card) onto the network. Each technology domain (Wi-Fi and mobile) treats the other as a complementary add-on to their service and centres the interworking on the native network architecture. Integrating both of these is necessary to serve the requirements of R&E users.

This technical paper is focused on network architecture for backhauling high-speed mobile and Wi-Fi in the context of R&E networking. The R&E networking model is accepted worldwide, with the community being served by NRENs at the national level, who in turn are connected to international R&E networks such as GÉANT. The current scenario in terms of Wi-Fi and mobile networking is analysed in Section 2. The corresponding proposals for network architectures for Horizon 2020 are outlined in Section 3.

2 Current state of high-speed mobile / wireless networking

2.1 What is high-speed networking

The design of network architectures for backhauling high-speed mobile/Wi-Fi networking is based first of all on traffic requirements. Requirements are generalised as bandwidth and QoS requirements. The current scenario and future projections can be estimated based on:

- Number of devices.
- Bandwidth available per device and per base station.
- The pattern of current traffic of mobile / Wi-Fi data.

Number of devices

The industry proposal for Horizon 2020 network architecture 0 considers the likelihood of one trillion devices being connected by that time. These will not only include the usual user equipment such as smartphones and tablets, but also smart watches, cars, houses and other connected equipment.

Actual data from events such as the TNC conferences show that the number of connected unique wireless devices is increasing at a much higher rate than the number of participants.

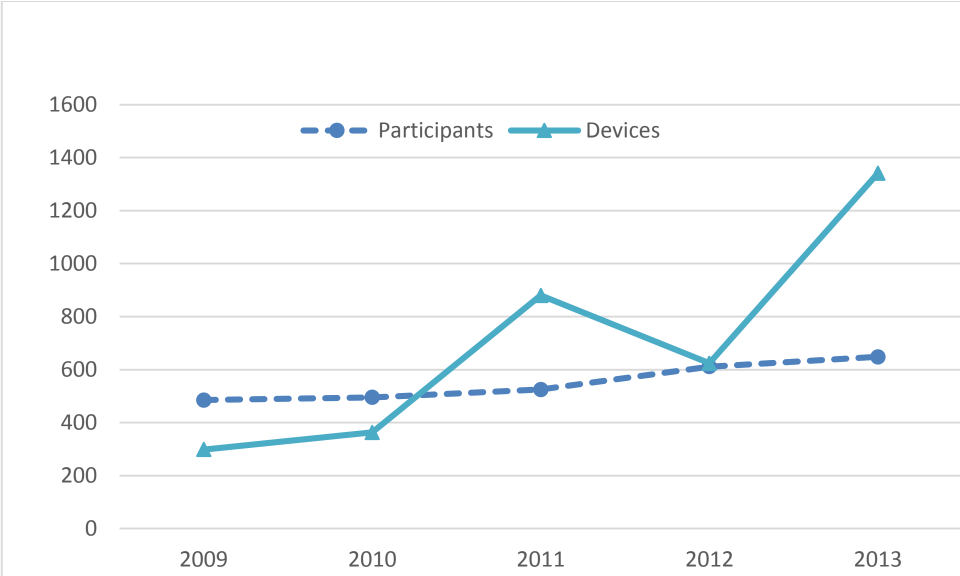

Figure 2.1 Unique devices trend during TNC conferences

The increase in user devices on Wi-Fi and mobile access networks will require these networks to be saturated with more base stations. The number of devices that are effectively served by an access point or a base station is decreasing with the increase of bandwidth requirements per device, so that cell sizes need to be reduced.

The data collected in terms of number of devices is inconclusive and does not allow a quantitative calculation of a possible projected traffic increase on the network, but is only useful in correlation with other data such as available bandwidth per device.

BANDWIDTH PER DEVICE AND PER CELL / ACCESS-POINT

The maximum theoretically available bandwidth per single spatial stream is 867 Mbps for IEEE 802.11ac, and the absolute maximum throughput is 403 Mbps for 3GPP LTE FDD on the physical layer [Johnson, C.]. Yet these maximum capabilities require all resources to be dedicated to the one channel and that there be no redundancy on the physical layer.

In a mobile environment (3GPP, LTE), terminals are typically dispersed over the cell area, so it is realistic to assume that all three possible modulations will be used. Assuming that 10% of the mobile terminals are close to eNodeB, 30% are at an intermediate distance and 60% on the cell borders, for the 4x4 MIMO configuration the maximum downstream cell bandwidth is estimated at 163.2 Mbps.

Taking into consideration that most LTE eNodeBs consist of three cells, then, based on the analysis provided above, the maximum mixed rate of the eNodeB is estimated at 500 Mbps. There are IEEE 802.11ac access points (APs) capable of reaching 1300 Mbps on the side of wireless PHY, but only when using a 1 Gbps Ethernet as uplink [NetGear AC1900].

The current bandwidth available per device and per cell / access point is in the range of hundreds of Mbps. 10 Gbps, or n times 10 Gbps network connections are required to feed an average metro or campus network consisting of 100<=k<=999 Wi-Fi/LTE cells.

TRAFFIC PATTERNS

Standards for 3GPP LTE-A 0 use IP as primary transport for both voice and data services. They specify 9 QoS classes. Each class is assigned an identifier, priority, packet delay budget, and packet error loss rate. Class parameters vary from the delay budget of 100 ms and packet error loss rate of 10^{-2} for conversation services to the 300 ms delay budget and no specified error loss rate. IP networks must support at least some of these classes. Percentage data for voice traffic with a strict QoS requirement was not available to the study group.

Long-term Wi-Fi traffic statistics from Vilnius University (VU, Lithuania) show that the amount of traffic is increasing steadily.

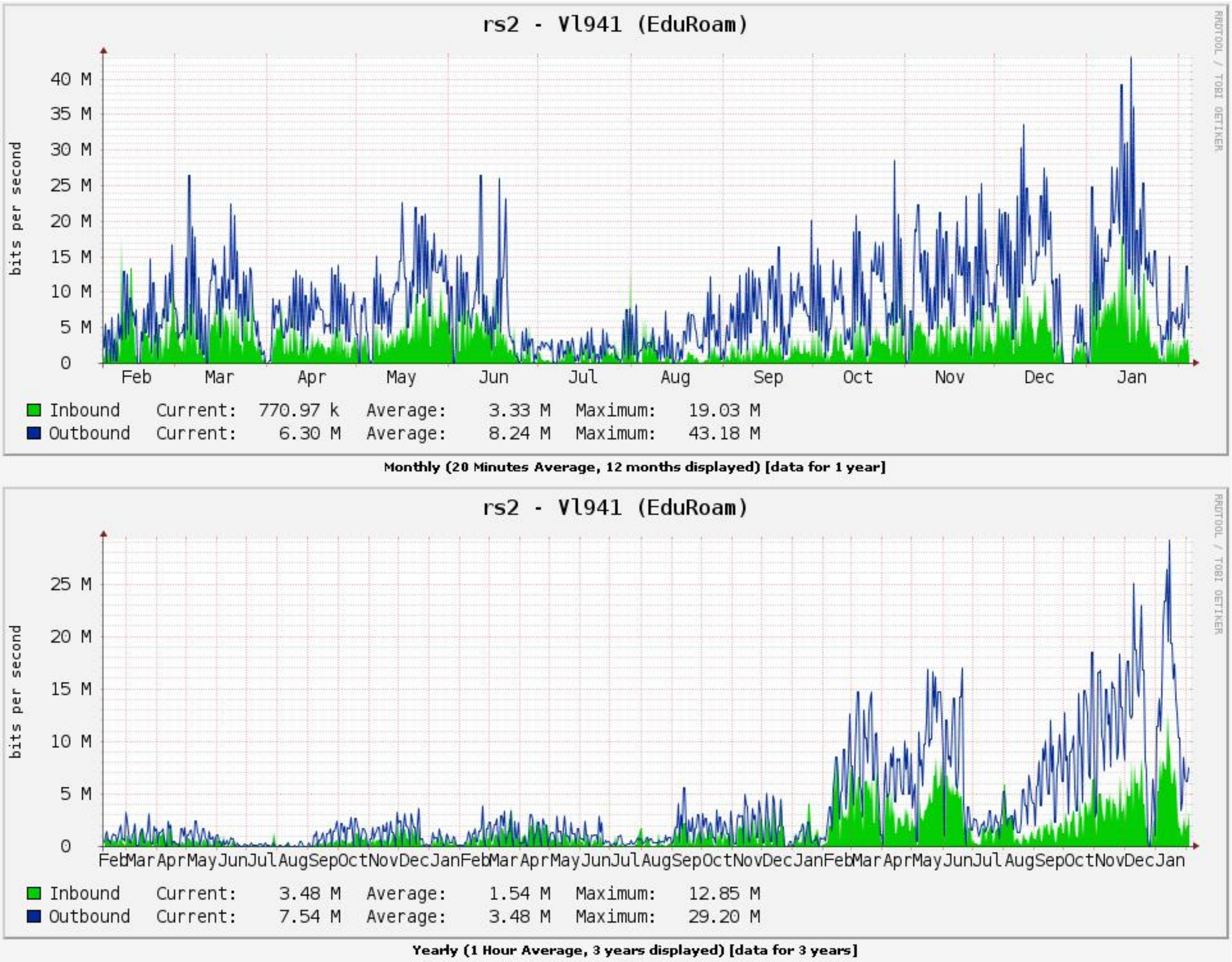

Figure 2.2 Wi-Fi traffic statistics from Vilnius University

Detailed traffic data from the Wi-Fi network of Kaunas University of Technology (KTU) has been analysed. The results are summarized in **Error! Reference source not found.**.

Provider type	Weekly		24h	
	Gbytes	Percent	Gbytes	Percent
Cloud providers (Google, Amazon, Microsoft, etc.)	98.5	14.30%	33.7	25.70%
Local traffic	111.6	16.20%	32.9	25.11%
Internet service provider networks	285.3	41.41%	36.5	27.86%
Content providers	79.5	11.54%	6.6	5.06%
Unknown type networks	11.5	1.67%	8.8	6.69%
Below TOP 50	102.6	14.89%	12.5	9.57%
Total traffic	689		131	

Table 1: Summary of top-50 ASNs by bytes transferred to the Wi-Fi network at KTU

Traffic data does not show any distinctive characteristics in terms of locality and directionality. Hence it is safe to assume that a high-speed mobile terminal produces/consumes traffic in the same way as a regular fixed computer connected to a high-speed network (e.g. FTTH), where the vast majority of the traffic is directed to the commodity Internet.

The study group considers that the traffic pattern will remain unchanged during the timeframe of the study. This means that an estimated 80 percent of all access traffic will originate from campus, NREN and GÉANT networks. The increase of access traffic will therefore impose requirements on the bandwidth of feeds from the backbone.

2.2 High-speed Wi-Fi deployment in R&E institutions

University campus networks have gradually evolved to provide a mix wired and wireless access. Surveys carried out have shown that most university campuses have deployed Wi-Fi in a mature campus-wide service, and that with a projected annual growth of 30 to 50 percent in user equipment alone **Error! Reference source not found.** t is becoming an integral part of university life.

Institutions have implemented a common wireless architecture based on thin APs that are connected to one or multiple controllers. This current solution effectively means that the same Wi-Fi wheel is re-invented at each institution. This means duplication of equipment, but also duplication of expertise and capacity needed to deploy and maintain the equipment at each institution. Surfnet's report on Wi-Fi deployment [Eertink, H.] backs this up.

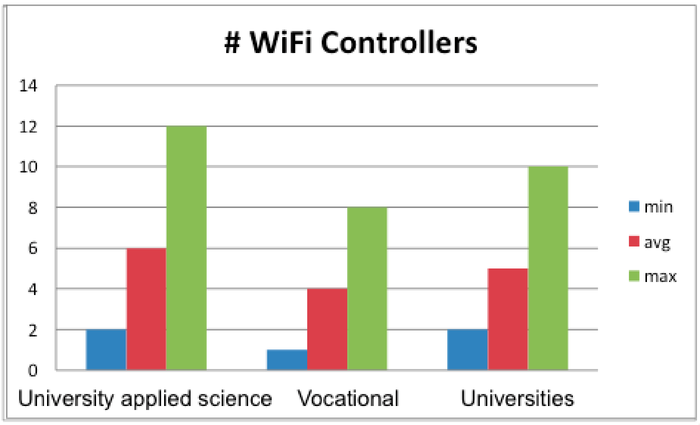

Figure 2.3 Wi-Fi controller deployment in R&E institutions in the Netherlands. Source [Eertink, H.]

This trend is not scalable in the long term:

- A single AP controller can only handle a limited number of access points (licenses), thus gradual growth results in several controllers being implemented throughout the network.
- Gradual growth results in different generations of hardware being installed on the same network service, meaning the network has to be upgraded on a per-AP controller basis.
- The manpower and expertise needed to deploy and maintain a Wi-Fi network at each individual institution (or school) involves a high use of resources.

From a Wi-Fi network planning and deployment perspective, an institute can be viewed in the same way as a large enterprise network with diverse and distinct requirements. What is ultimately going to affect client devices more than any other factor is the degradation of signal-to-noise ratio (SNR) through both co-channel and adjacent channel interference driven by co-located devices. Proper system engineering can minimise the impact of this by maximising proper spatial reuse, but not eliminate it entirely in highly dense environments, such as auditoriums, as changing an operational parameter in this kind of environment has much more impact than in a regular enterprise or on customer premises. Proper system architecture is therefore a key element in ensuring the scalability and reliability of a high-speed Wi-Fi network so that it is easy to maintain and adapt to an ever-changing environment.

As is shown in Figure 2.4 below, hardware is only responsible for 20% of the deployment costs of a Wi-Fi access point. The increased complexity of maintenance of Wi-Fi networks, together with the relatively high percentage of deployment costs involved in the planning, pre-planning, installation and commission of a Wi-Fi access point, could be a reason for NRENs to offer Wi-Fi as a service to institutes (see Section 3.2.).

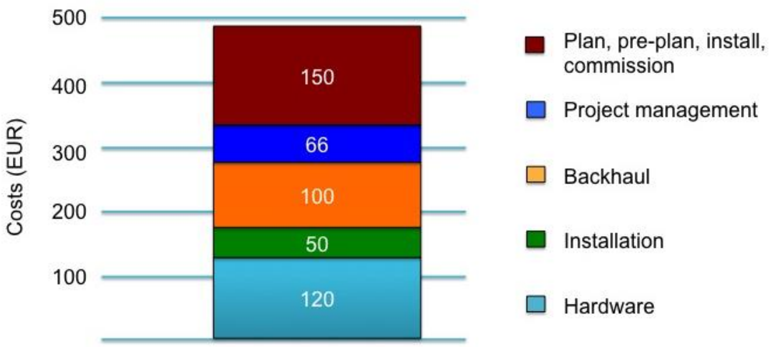

Figure 2.4 Deployment costs of an indoor Wi-Fi access point [source: Analysis Mason 2011]

The deployment of high-speed Wi-Fi networks in an R&E institution is a complex task that requires a wide variety of network architecture parameters to be taken into consideration. Not all institutions and still fewer schools and vocational training centres have such expertise.

2.3 Wi-Fi and mobile: bridging the gap

The Position of NRENs (between institutes and operators)

Mobile and Wi-Fi data connectivity are two complementary network technologies that both provide access to learning and other services accessible via the Internet. Universities, research institutes, schools and other home institutions provide Wi-Fi for R&E community members. Commercial MNOs are traditionally responsible for providing mobile connectivity to the same set of users. The providers of these services are of different scales. Even the largest R&E institutions (universities) are not comparable in size to MNOs, thus they do not have the capability of creating an effective business case for MNOs. Only the united resources of NRENs and GÉANT are in a position to perform this on a national and international scale.

A 2013 GÉANT mobile connectivity business case study [DS3.5.1] shows that only 9 out of 38 GÉANT partners are providing mobile services to the community in one way or the other. Integration with the networks of R&E institutions is proving to be difficult. The main difficulty lies in a difference of paradigm:

- Mobile operators are historically focused on voice communications and consider data and video over Wi-Fi as complementary services. Their operations are based on the vast networks connecting large numbers of devices and multi-national operations.
- NRENs have a long history and experience in computer and data networks and therefore tend to view mobile data services as a (slower) complement to wired and Wi-Fi data communications.

Extension of campus networks

Eduroam has already proven successful with 5885 connected sites in 54 countries on all continents except Antarctica [eduroam], and large numbers of researchers and students using eduroam for their specific research needs as well as simple Internet access. Nowadays eduroam is limited to the areas covered by the Wi-Fi networks of the participating institutions – mainly university campuses.

While eduroam is now available in some places and at a few events outside campuses, these are very limited in number. They include a few city centres, some airports (permanent access) and a few conference centres where eduroam is offered for some specific events (ad-hoc access for the duration of the event). In these instances it is offered by third-party (not research and education) providers, but user authentication is carried out by research networks. Eduroam access is free for users, who do not have to pay the Wi-Fi providers for the service. Also the NRENs do not pay the Wi-Fi providers for providing eduroam in their infrastructure. In some cases research networks backhaul eduroam traffic from the Wi-Fi infrastructure. In this way, Wi-Fi providers can reduce expenses on their Internet subscription and eduroam users receive potentially better service as their traffic to their home institutions uses research networks that should ensure better transmission parameters (e.g. bandwidth, packet delay). Eduroam is offered to the R&E community by the Wi-Fi providers as one of the services in the Wi-Fi infrastructure, together with public Internet access (Internet access for the whole user population) and/or Internet access for other closed user groups (e.g. customers of the Wi-Fi provider).

Campuses and on-campus networks do not have enough capacity to support all student learning capabilities. Current experience proves that eduroam access does not have to be limited to campuses and can be provided in wider areas without any significant cost to the research community. Third-party Wi-Fi infrastructures can be successfully used to provide eduroam access outside campuses, which would be of benefit to the research and education community, but wide-area/national coverage is not realistic using Wi-Fi technology alone. Research institutions will have to complement this with mobile services in order to create a network accessible from anywhere.

Mobility and Handover

Integrating different wireless access technologies to provide users with data services will result in the creation of a heterogeneous radio access network (HRAN), e.g. Wi-Fi and mobile networks operated by an entity to provide data services to its users. User equipment (UE) is usually capable of managing one interface for Wi-Fi, and another for mobile communications (4G/3G). Moving from one wireless domain to another, e.g. from an indoor Wi-Fi area to the outdoor 4G/3G area, causes traffic to be switched from one interface to another as shown in Figure 2.5. This usually results in the reestablishment of a TCP connection due to the change of IP address assigned, and therefore in application disturbance. It is expected that in future users will be as highly mobile with their UEs as they are today (or even more so). Consequently, UEs may frequently perform handovers and users may be forced to perform re-logins or application restarts, which could undoubtedly jeopardise the quality of their experience.

This problem is defined as the vertical handover problem, where UEs change their connections from one type of access technology to another, resulting in connection reestablishment waiting time. As mobility is becoming more and more important, especially as wearable devices and vehicular connections grow in popularity, the vertical handover problem is not a trivial one. Thus it is a good time to start considering the possible solutions for future European R&E networks.

Currently, there are two main approaches towards resolving the problem of vertical handover. The data offloading approach is widely adopted by the industry [Pries, R. et al]. This mainly addresses the issues involved in UE handover between different technologies, but between mobile and Wi-Fi networks operated by a same entity, so still within a same provider domain. The other solution [Interworking Wi-Fi and Mobile Networks] offers seamless integration that does not require the UE to reconfigure the IP portion of its stack, so that the same IP address may be used, thereby providing uninterrupted communications. However, the more common situation in the R&E community is to have separate wireless technology domains operated by different entities in geographical proximity to each other, making its reality more complex than that presented by the homogeneous operation of a single-provider network. The handover technologies currently available in practice mandate a change of IP address in the event of UEs transitioning between different domains. This means that applications have to implement measures to support communications, resulting in a greater use of user equipment resources [Kreibich, Ch. et al]. Experimental implementations for relieving IP semantics overload are available [Meyer, D. et al]:

1. Locator-Identifier Separation Protocol LISP, RFC 6830
2. Proxy Mobile IPv6 PMIPv6, RFC 5213 [Gundavelli, S., Leung, K., Devarapalli, V., Chowdhury, K., Patil, B.]
3. RINA [Trouve, E. et al]

The R&E community model spans multiple domains while still serving a closed user group. This gives the R&E community a strong position as a potential test bed for vertical handover across different domains.

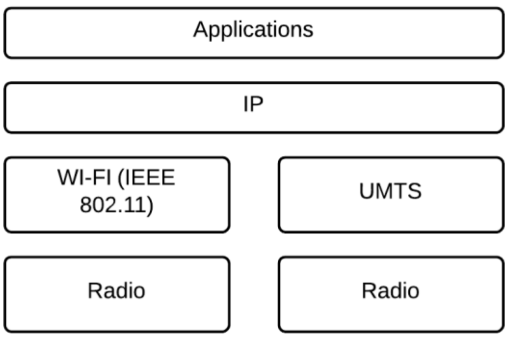

Figure 2.5 Network stack operation for vertical handover.

3 Proposed network architectures

3.1 Core and backbone network architecture considerations

There follow some basic recommendations for core network design for efficient aggregation of high-speed mobile data, taking into consideration the specifics of the R&E networking environment:

1. Capacity dimensioning of the core network must take into consideration the fact that during peak periods the additive traffic load due to high-speed mobile data backhauling may scale to multi-Gbps speeds. It is best for an NREN to handle this additional traffic at a low layer instead of dealing with it at the IP layer, as explained below.

2. Investigate the economics of sustaining peerings with the commercial Internet close to the interconnection point of the aggregation network and the NREN network. In this way the NREN network is offloaded from carrying large amounts of data which leads to serious investments in CAPEX (e.g. DWDM transponders, router linecards).

3. If investment in sustaining multiple peerings with the commercial Internet is not advantageous, then the NREN could examine the option of establishing direct tunnels to the closest Internet peering so as to minimize packet processing and achieve improved delay performance. This can be performed by installing either dedicated wavelength or lower granularity OTN circuits connecting an NREN router that directly interconnects with the aggregation network with an NREN router that peers with the Internet (Figure 3.1). Both options guarantee low delay and respect of the QoS constraints; with dedicated wavelengths, imposed delay is dominated by the unavoidable propagation delay and to a lesser extent by the FEC processing. In OTN circuits the additive delay of OTN switching is also imposed; in all cases imposed delay is lower than using layer 2 protocols such as MPLS-TP or regular layer 3 IP routing. By comparison with the established practice of using direct wavelengths with OTN circuits, it should also be noted that, despite the fact that the direct wavelengths solution can offer higher bandwidth, it does not present adequate protection performance characteristics unless the expensive 1+1 protection scheme is adopted. More specifically, wavelength restoration requires deployment of directionless ROADM filters which are quite expensive and can be reconfigured in seconds compared to OTN circuits where protection paths can be activated within less than 50 msec.

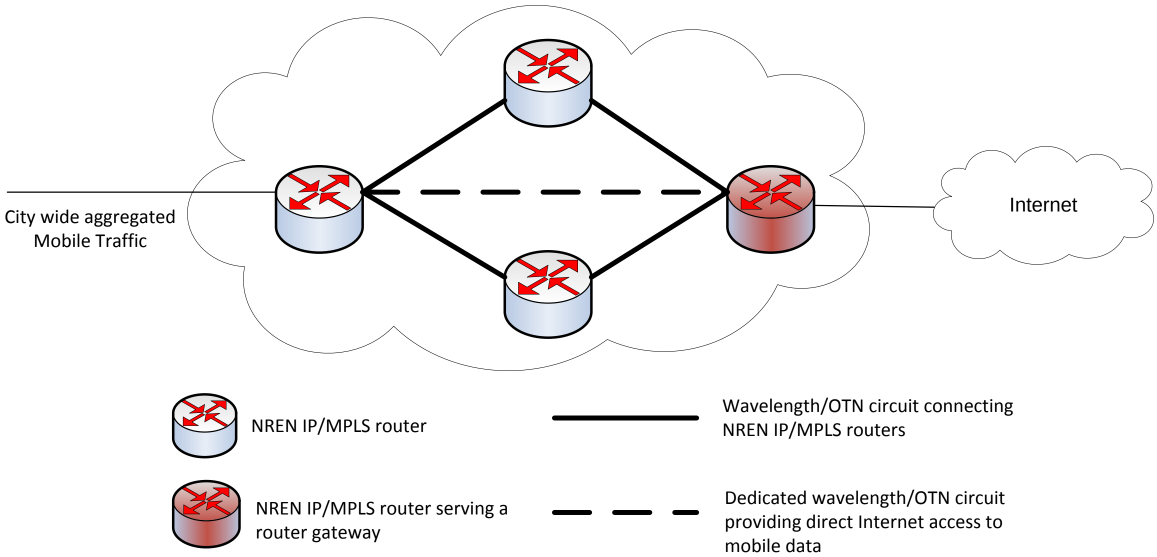

Figure 3.1 Providing dedicated wavelength/OTN circuits for accessing the Internet

3.2 Wi-Fi as a service (WaaS)

Wi-Fi-as-a-Service (WaaS) is driven by the popularity of Wi-Fi deployments and the increased expertise and capacity needed to deploy a Wi-Fi network at a professional level at each institution individually. There follows an outline, both from a technical and a business case perspective, of how NRENs could offer an added value to institutions by providing WaaS. WaaS is not a new concept in itself; there are already cloud providers who offer this service on a commercial basis (see e.g. http://waas.nl). They can do this because vendors sell controllers that can handle tens of thousands of clients and 6000+ access points. For NRENs – who are used to clear and simple demarcation points – WaaS is however very new. Various WaaS solutions are possible, ranging from only delivering a controller backend to offering a complete managed service that includes the procurement and installation of access points.

The implementation of a WaaS solution on a European scale poses many questions. On such a scale, it is expected to encounter potentially blocking challenges in terms of organization, support and technical constraints. However, NRENs share many commonalties which make cooperation among them in delivering WaaS potentially very fruitful. To make progress towards the provision of WaaS, from the technical point of view NRENs would need to:

1. **Define the optimal system architecture for WaaS**. Proper system architecture is the key element to ensure future technical success. It is not sufficient to specify what the architecture can do but it becomes increasingly important how easy it is to use, how scalable it is and whether it can adapt over time (in capacity, usage, etc.) to guarantee availability of the WaaS service as well as support various migration scenarios.

2. **Establish federated WaaS management**. The rationale for WaaS stems from the principle that it is more cost effective to manage a Wi-Fi network from a central location, rather than at each individual institution, which also leads to a better user experience. This requires a common set of conditions and policies that prevent it from becoming unmanageable over time. These include a clear separation of responsibilities: What falls under the responsibility of the NREN and where does this responsibility end? Who fixes what if the service is not available? What actions should the institution take? When can an institution contact the NREN (if an access point does not function, if users cannot authenticate, if users cannot get on-line, if only some of the users cannot gain access…)? Ideally, the management platform will allow detailed monitoring such that issues become evident and can be solved before the institution receives complaints.

3. **Define common functional requirements and policies**. Institutions should be in the driving seat and define policies that must be enforced by the Wi-Fi network. It is important to understand what the minimum common denominator is for the most important policies from the R&E community, as the desire to offer a unified solution may lead to a situation where it might not be possible to enforce all policies. As an example, distinguishing various user groups (student, guest, personnel…) and handling them differently is an obvious functional requirement; for one institution the support of various user groups may be sufficient but others may want to define policies for end-to-end security. Consequently, they may want to define which services can be discovered via Wi-Fi, who has access to them and from where can they have access to which application. While the WaaS solution should simplify the life of institutions it should not lead to a lack of support for their most common policies.

4. **Guarantee the ultimate end-user experience**. This includes easy access to the Wi-Fi network (for students, staff and guests), a common way to identify rogue devices and to place them in quarantine, helping individuals when they experience problems with Wi-Fi performance or availability, and quality/capacity planning that ensures hassle-free access from all places.

5. **Establish the prerequisites for the application of WaaS**. The prerequisites for offering WaaS to an institution may include availability of good access switches that are connected with (two) proper cables (> cat 6e), support of PoE, and no restrictions on placement of access points. WaaS may also be used to offer Wi-Fi during events, in which case setting-up a tunnel between access points and controller that carries both signalling and data is important because this limits the need for support at the location where the event is organised. Ultimately, these prerequisites should be captured in a WaaS service level agreement.

3.3 Integrated access network architecture

NREN network architecture considerations

The JRA1 T3 research group considers LTE and LTE-A as the main mobile technologies that are most likely to be implemented by mobile network operators within the next five years. We foresee two technical possibilities for integration of LTE with R&E institutions:

1. In the first scenario, NRENs function as a single bridge to connect the ICT infrastructures of institutions with mobile operators. In this case, the institutions hold a contract with a mobile operator and the NRENs

bridge the domains from the technical point of view. In this scenario NRENs will have to implement two distinct paths for data forwarding: '*institutional traffic*' and '*generic traffic*'. The former will guarantee access to the home institution's resources while the latter will carry general commodity Internet and R&E traffic.

This type of connectivity requires double authentication using both SIM cards and home institution credentials, and home institutions may apply their own policy decisions as to which users may use which data path.

Generic traffic could be switched off directly at the NREN backbone closer to the exchange points where every destination is topologically "nearer" as recommended in 3.1. Proposed data paths are shown in Figure 3.2

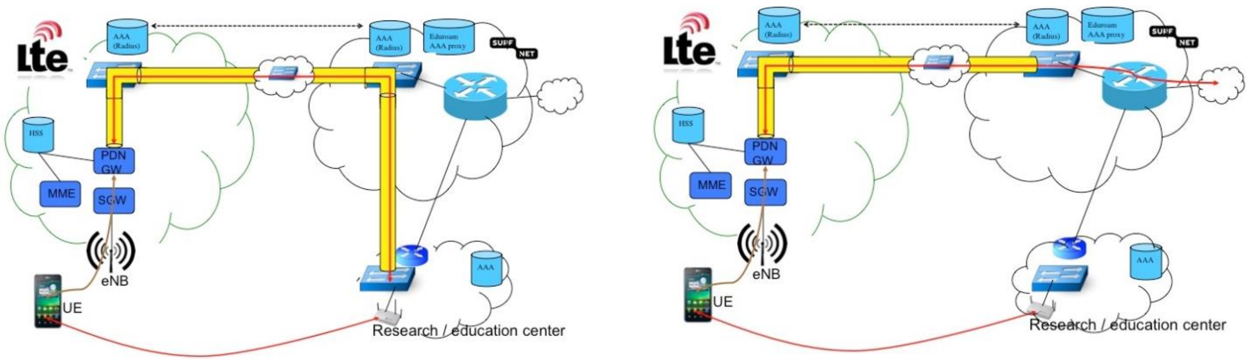

Figure 3.2 Network architecture for the backhaul of LTE mobile networking

2. In this scenario, the NREN acts as an MVNO and offers 3G/4G subscriptions to its customers. In this case, the NREN can rely on 3GPP standards to integrate the different access networks. Interoperability between Wi-Fi and LTE (including vertical handover between Wi-Fi and LTE) is the key aspect of this integration scenario. This holds in particular when combined with offering Wi-Fi as a service (see Section 3.2). This integration is not possible in the previous solution. In addition, this solution also allows services to be offered beyond the boundaries of the NREN's home country. It also allows international roaming when NRENs in different countries cooperate with one another.

   The approach defined by standards [E-UTRA]**Error! Reference source not found.**, [Soliman, H.], 5213 Gundavelli, S., Leung, K., Devarapalli, V., Chowdhury, K., Patil, B.] and adopted by the industry [Interworking Wi-Fi and Mobile Networks] is a provider-centric one:

   a. Trusted access is only from within the same infrastructure provider while anything else is considered "untrusted", with the resulting service limitations. R&E institutes, NRENs and GÉANT form a multi-domain trusted community spanning multiple infrastructures.

   b. Wi-Fi access is homed to the mobility anchor (MA) that is a part of EPC and all the data passes through P-GW. This may not be the optimal path for the data IP-wise, and the distinction between "*institutional traffic"* and "*generic traffic*" deviates further from the optimal path. This approach also faces scalability problems as more traffic is routed towards the MA.

Current network architectures for integrating Wi-Fi and mobile (LTE) services do not reflect the model of operation of research networks. The R&E community may adopt the above industry-standard approach as a test and workaround to foster the initial take-up of the service, while proposals for a completely new architecture could be devised to enable seamless integration. The R&E community has the necessary experience and expertise, but close collaboration with the industry has yet to be achieved. Support from industry and standardisation bodies will be essential to implement integrated access architectures.

Extension of campus Wi-Fi network

Eduroam is a successful way of accessing the wireless network at the premises of participating institutions, mainly university campuses, research institutes and education facilities. This document proposes the extension of eduroam coverage beyond university campuses to city centres, airports, hotels, recreation areas, etc. As it is not possible to use the Wi-Fi infrastructure of participating institutions outside their premises, it is assumed that the access infrastructure of other (non-academic) institutions will be used for eduroam access.

It is assumed that cooperation for extending eduroam will be established with Wi-Fi providers who already offer Wi-Fi connectivity for free as part of their public mission (e.g. municipalities) or in order to promote the sales of other services (e.g. restaurants, pubs). As Wi-Fi is not a direct source of income for such providers, providing eduroam access will increase the value of their Wi-Fi service and will not affect their income. Wi-Fi providers who sell their Wi-Fi services directly to customers may not be interested in providing eduroam access for free to eduroam users, as this would potentially decrease their income from their Wi-Fi services. Cooperation with this group of providers is outside the scope of this document.

There are two general areas in which eduroam could be offered outside the premises of participating institutions. Permanent access to eduroam would be useful in places where eduroam users can access the service over a long period of time (permanently), while ad-hoc eduroam access could be deployed in places where a large number of eduroam users can access the service over a short period of time. This might happen for example on the occasion of events such as scientific conferences and other types of events, e.g. concerts, music festivals, sporting events, etc.

Vertical Handover for Campus and Aggregation Networks

The proposed solution for vertical handover aims at making the handover process transparent to the UE so that the UE does not have to perform any complex algorithm or application restart. The proposed methodology is to utilise the SDN approach to implement cooperation between the existing Proxy Mobile IPv6 solution in the Wi-Fi domain and the Evolved Packet Core (EPC) in the mobile communication domain. In order to do so, the OpenFlow protocol can be implemented in several functions/nodes: LMA, MAG, eNB, and RRH. By adopting a single OpenFlow controller in the HRAN, handover information can be centrally processed by the controller and corresponding changes in behaviour can be carried out in order to provide seamless vertical handover.

Wireless detachment and attachment processes would still be handled by the existing standard. However, improvements could be introduced by the OpenFlow controller changing the flow tables of the switches/routers that are on the data path of the mobile node (MN), after changing the point of attachment. In other words, the signalling path would use existing standard PMIPv6, but the data path could use OpenFlow supported routers to facilitate fast data flow switching.

This change from automatic to software-defined packet forwarding will need strong support from the industry. In addition, standardisation of the northbound APIs and west-eastbound APIs should be carried out before this can happen. In case more controllers are needed to solve the scalability issue due to too many handover requests, communication protocols among controllers will be crucial.

4 Conclusions and discussion

1. Research and education networks need to evolve to meet the requirements of new learning paradigms for ubiquitous network connectivity.

2. The JRA1 Task 3 research group proposes that the following network architectures be implemented or developed within the research and education network community:

    2.1. NREN and GÉANT backbone and core traffic should support data rates up to several tens of gigabits per second for backhauling high-speed Wi-Fi and mobile traffic. These networks should have the capability to switch aggregated traffic from aggregation networks to the points where the data path will be optimal to reach most Internet destinations.

    2.2. NRENs should try to address the high-speed Wi-Fi requirements of all connected institutions including small schools, vocational training centres and research institutes who do not possess sufficient expertise to deploy complex access networks. The deployment of a Wi-Fi-as-a-service platform will provide added value to the research community by enabling all institutions to focus on the primary business of education rather than reinventing the wheel of Wi-Fi network setup.

    2.3. Research and education networks should make an effort to produce a fully integrated solution for institutional Wi-Fi and mobile domains in a multi-domain, multi-infrastructure environment. Campus networks should be expanded using third-party infrastructures. R&E networks must adapt and test integration and mobility technologies.

3. The following are points for discussion and further study:

    3.1. Existing content makes the learn-as-you-go use of network the commodity within the communities in universities, colleges, institutes, and even schools. Wi-Fi and mobile comprise the ultimate access media for the foreseeable future. The development and implementation of new architectures will more likely affect access and aggregation networks, that is, universities and NRENs in the R&E networking environment. International cores such as GÉANT will only experience a growth in commodity traffic and the requirement for QoS in certain cases.

    3.2. We believe that the integration of Wi-Fi and mobile technologies will be a long and gradual process. The challenge will be to achieve seamless network connectivity between the various radio networks without disturbing applications that make use of these networks. It is noted that such an integrated solution will need to bridge several administrative domains, which limits flexibility in handling data and/or signalling traffic. Close cooperation between NRENs and mobile operators is needed to accomplish this integration, considering that Wi-Fi traffic exceeds 3G/4G traffic in order of magnitude and therefore requires different solutions to those currently recommended by the standards. Sending and receiving of data over 3G/4G networks is the core business of mobile operators and they expect to be paid for delivering that service.

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Glossary

API	Application Programming Interface
eNB	see ‘eNodeB’
eNodeB	Evolved Node B (also abbreviated ‘eNB’)
EPC	Evolved Packet Core
HRAN	heterogeneous radio access network
IP	Internet Protocol
IPv6	Internet Protocol version 6
LMA	Local Mobility Anchor
LTE	Long Term Evolution
MA	mobility anchor
MAG	mobile access gateway
MNO	mobile network operator
MVNO	mobile virtual network operator
NREN	National Research and Education Network
PoE	Power over Ethernet
QoS	Quality of Service
R&E	Research and Education
RINA	Recursive Inter Network Architecture
RRH	remote radio head
SDN	Software-Defined Networking
SNR	signal-to-noise ratio
UE	user equipment
WaaS	Wi-Fi-as-a-Service