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mesh-wise

Self-organising MESH Networking with Heterogeneous Wireless Access

D3.1: *System requirements for mesh applications in the smart city & emergency contexts*

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0 Introduction

0.1 Current Technologies

In a contemporary urban environment there are a large number of different telecommunication technologies used, due to the diverse requirements of the users and the applications, but also the necessary compatibility with older devices. The majority of the broadband connectivity in the cities is based on the DSL technologies (Table 1). The advantage of DSL technologies is the use of the copper-wire telephone network infrastructure that dominates all cities worldwide. There are a few, mainly experimental, installations of fibre optic networks for the subscribers' access that follow the naming convention of FTTx. Therefore FFTx covers the following architectures: fibre-to-the-home (FTTH) and fibre- to-the-premises (FTTP), fibre-to-the-building (FTTB), fibre-to-the-curb (FTTC), and fibre-to- the-node (FTTN). Both FTTN and FTTC provide actually a service based on DSL, providing the advantage of the short distance, thus better throughput. On the other hand, FTTH and FTTP can offer a true high bandwidth and symmetrical performance to the end user, as it actually offers direct Ethernet connection with rate up to 1000Mbps in some cases.

Table 1 Typical landline connections for home access

Name	Standard	Downstream (Mb/s)	Upstream (Mb/s)
ADSL2+	ITU G.992.5	24	1.1
ADSL2+M	ITU G.992.5 Annex M	24	3.3
VDSL	ITU G.993.1	55	3
VDSL2	ITU G.993.2	100	100
FTTx	IEEE 802.3ah-2004 / EPON	31-1000	31-1000

Further than the typical landline access the wireless technology has advanced significantly and the penetration of the wireless and mobile networks is continuously increasing. The bandwidth offered through the wireless medium is comparable to and in many cases better than the typical DSL performance (Table 2). The wireless paradigm is quite attractive, especially in rural areas where there is absence of proper landline infrastructure, but also in urban areas where the condition of the telephone network is not suitable to provide adequate throughput. Furthermore, the rapidity of the deployment and the lower cost of the investment draw the interest of the providers as well.

Table 2 Wireless standards - technical info & performance

Standard	Streams	BW (MHz)	Downstream (Mb/s)	Upstream (Mb/s)
IEEE 802.11n-2009	1-4	20 - 40	150 (40MHz – 1 stream)	150
IEEE 802.11ac	1-8	20 - 80	200 (40MHz – 1 stream)	200

HSPA		5	14.4	5.76
HSPA+	2	5 - 20	84	22
LTE	1-4	1.4 - 20	300	75
802.16-2009	1-4	1.25 - 20	141	138
802.15.4	1	2	0.250	0.250

The most resilient but at the same time expensive to use technology is the satellite. Typically, satellite provided Internet is based on a geostationary/geosynchronous orbit satellite fleet that mainly acts as a relay between earth endpoints. Although satellite provided entertainment services (TV, radio) are quite popular, the Internet service is used by a small group of users. The main reasons behind that are the high cost, low bandwidth, high delay, and installation complexity. The only parameter that is impossible to override is the delay, as the geostationary orbit has a propagation delay that is about 250 ms. Low Earth Orbit (LEO) satellites have a significant reduction to 80 ms to 10 ms. The low bandwidth that is offered by the Ku-band satellites (typically up to 1 to 2Mbps) has been overhauled by new satellite networks at the Ka-band that offer up to 20Mbps downlink and 6Mbps uplink.

0.2 Evolution towards Smart Cities

A smart city further than the human/social aspect and the quality of life that should offer, it requires the existence of a modern, robust and sustainable communication infrastructure. The applications that differentiate and elevate a city to smart one require the aforementioned infrastructure. Mesh networking can provide the characteristics that are necessary to support the intelligence of the software infrastructure that drives the growth of a smart city. The Internet of Things (IoT) and Internet of Services (IoS) models will eventually be the substrate of any smart city. Therefore a platform that supports two levels of abstraction: (a) the infrastructure level where the IoT supports the complex, heterogeneous and dense deployment of devices and sensors, and (b) the service level where the IoS orchestrates the open, standardized and interoperable services of the smart city. A unified urban scale ICT platform is required to provide three core functionalities: communications abstraction, unified information models and open services development. The broad and diverse set of heterogeneous usage scenarios also determines and affects the heterogeneity of the supporting communication layers. Therefore, the communication abstraction will allow unified communications and services regardless of the underlying different networking standards. The abstraction will be responsible for the agnostic, to the masked connection protocols, data transfer services. Open, easy to use and flexible interfaces are required in order the users involved (public administrations, enterprises, citizens) to be able to interact and manage all aspects of the urban life in a cost-effective way. This will enable innovation and attract the necessary investments in order to build and retain a sustainable ecosystem. The smart city ecosystem will promote the production of large-scale deployments of applications and services, for numerous activity sectors. Large-scale comes with the requirements of intelligent design and infrastructure, in contrast to a typical, simple collection of interconnected networks, in order to be robust and sustainable. A universal, ubiquitous platform can provide the infrastructure that will allow the cost efficient integration of heterogeneous and geographically disperse sensors, devices and services into a common technological basis.

Source: Beecham Research, *M2M/IoT sector map*, 2013.

Graphic: Deloitte University Press | DUPress.com

Figure 1 The Internet of Things, proliferation of connected devices across industries, applications and devices [1]

0.3 Trends

The driving force behind any infrastructure development and investment are the socio-economic trends that influence the adaption and penetration of ICT into the customer base. The usage and traffic of the Internet per capita is continuously increasing with the leading North America region to have over 50 GB per month and Europe follows with about 35 GB (Fig. 2). As the video streaming services are becoming more popular this number will continue to increase rapidly. The less economic advanced world is quite behind, and this proves the economical aspect of the Internet growth. Further than the aggregate numbers of traffic, a more detailed analysis on the type of data transferred offers a better insight of the leading trends and the future requirements. A proper study of these requirements will provide the guidelines for the development of future proof and robust networking infrastructures.

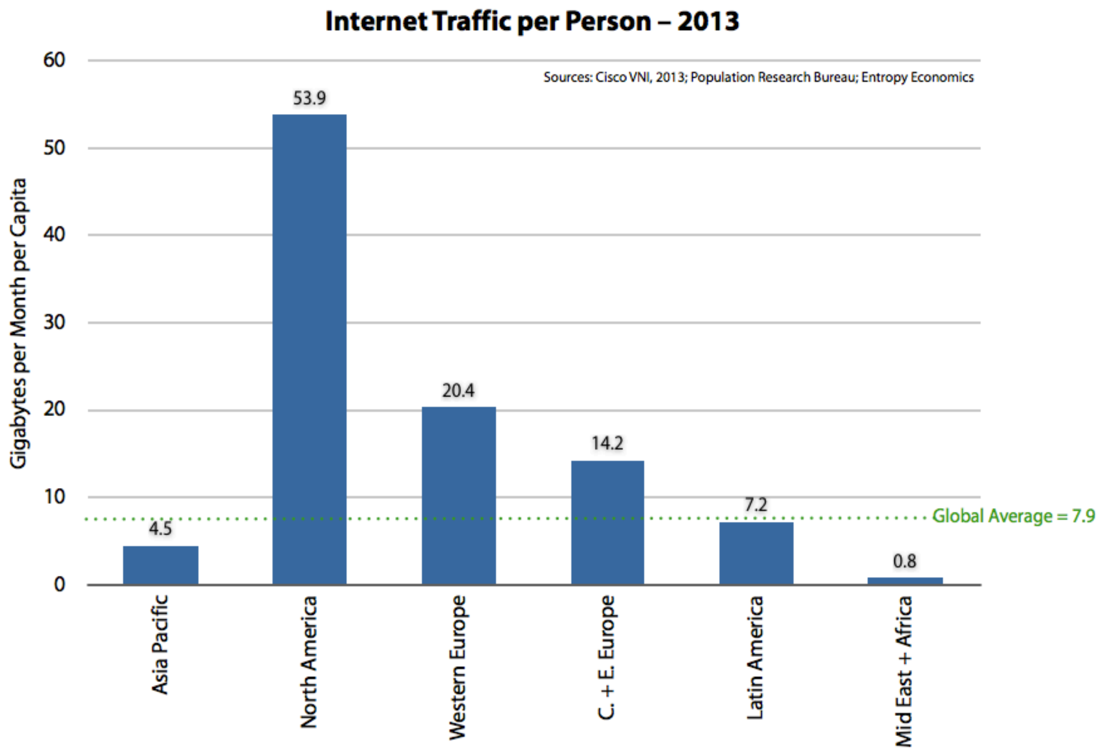


Figure 2 Global Internet traffic per capita, per month for the year 2013 [2]

0.3.1 Mobile and wireless service trends

The most certain prediction for the future is that the majority of all types and kinds of devices will incorporate a wireless communication technology. In the following sections we concentrate on the current predictions on the distribution of the type of the mobile devices, the traffic that the mobile networks will have to support, the type of the applications, which will consume the majority of the data and the extreme machine-to-machine traffic rise of 89% in 5 years (Fig. 3).

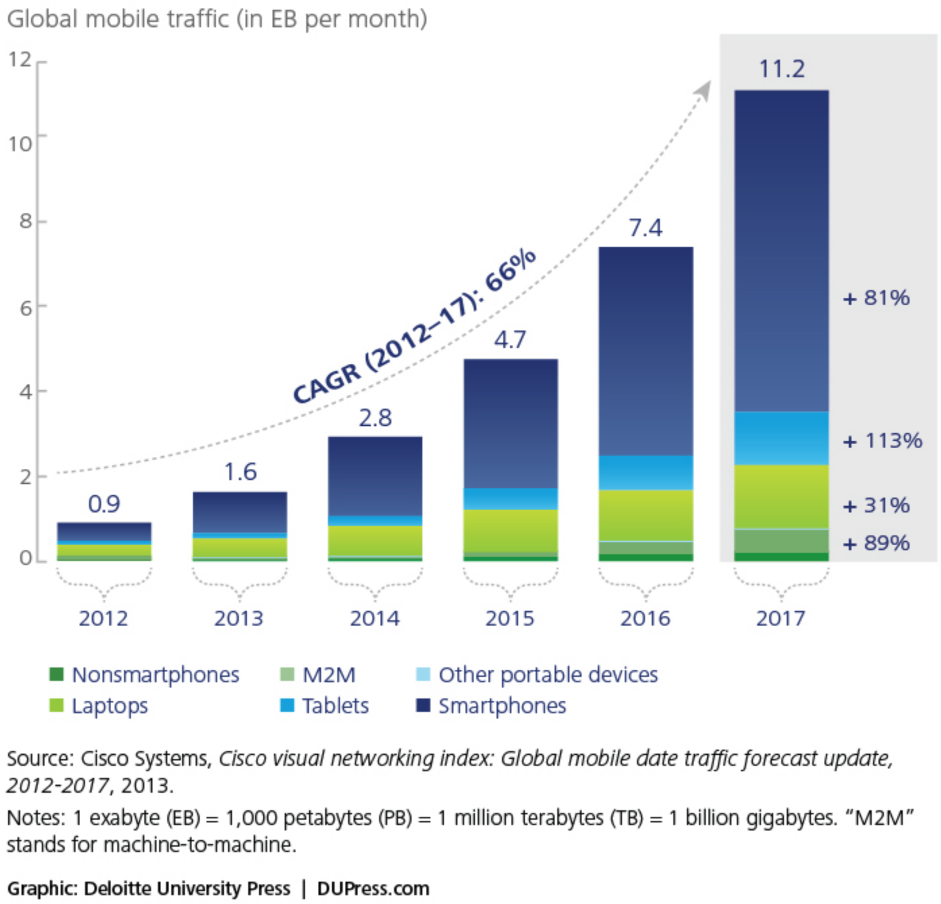


Figure 3 Global mobile traffic distribution prediction [1]

0.3.1.1 Mobile devices diversity

Until few years ago the big majority of mobile devices were the mobile phones. This has started to change significantly since the appearance of the touchscreen smartphones back in 2007-2008. In the years to come the smartphones will overtake the standard mobile phones in number (Fig. 4). At the same time a significant percentage of mobile devices will be machine-to-machine (M2M) apparatuses that is calculated to be about 20% by the year 2018. Tablets follow a similar increasing path and along with laptops are going to be a little less than 10% of the total mobile devices in four years from now. Moreover in Fig. 5 the predicted shipments of users' devices depicts the clear aggressive increase of smartphones and on the same time the slow degradation of PCs sales.

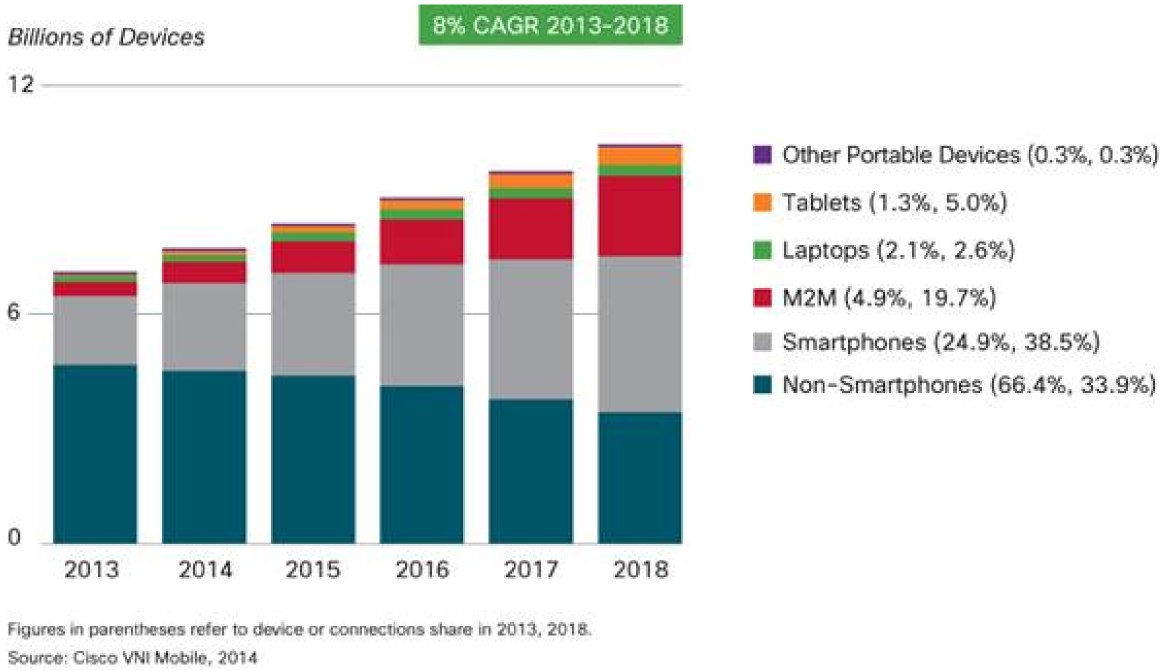


Figure 4 Prediction of the devices' distribution up to year 2018 [3]

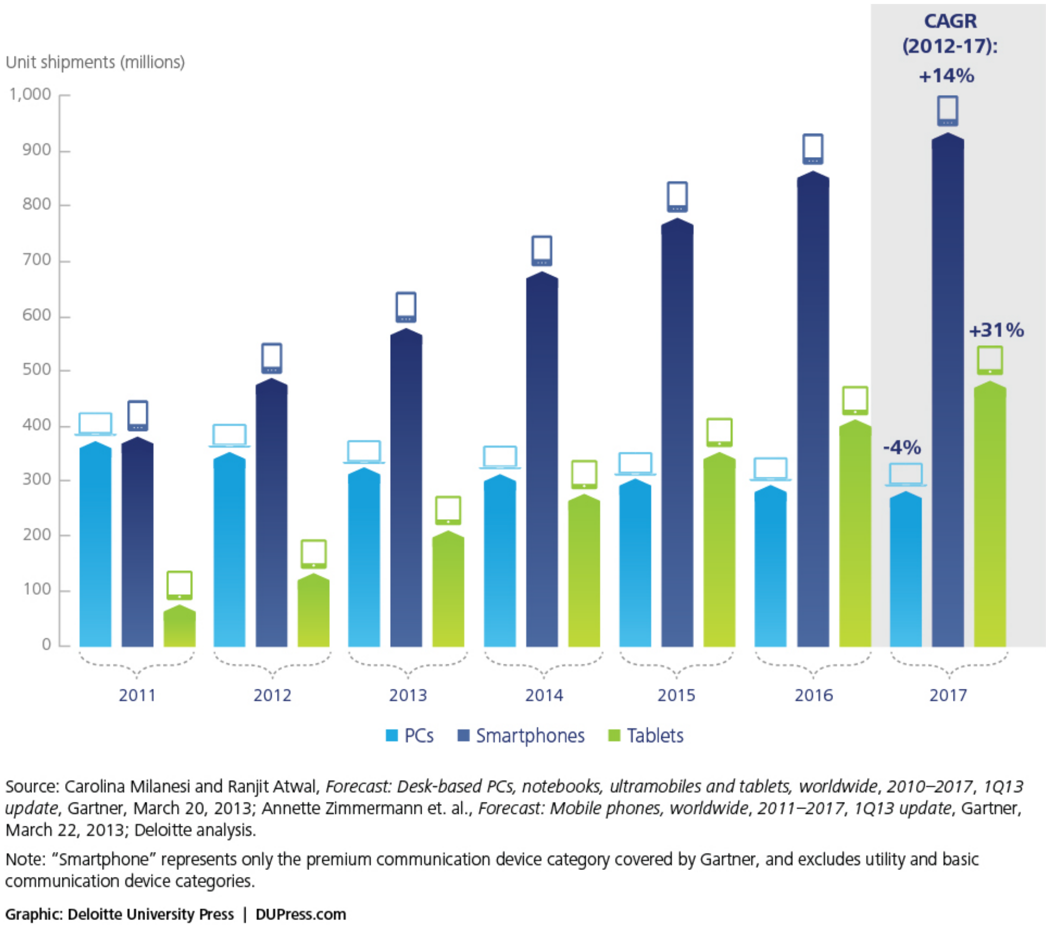


Figure 5 Expected user's devices shipments [1]

0.3.1.2 4G adoption

At the present time over 60% of the mobile traffic is performed on 3G networks. LTE or 4G networks have not established a position yet to absorb a large amount of the traffic, although their capacity is significantly larger than the 3G ones (Fig. 6). Therefore currently traffic over 4G networks corresponds to the 30% of the total. The trend shows that the balance will change within the next 3 to 4 years where 4G is going to overwhelm the 3G traffic.

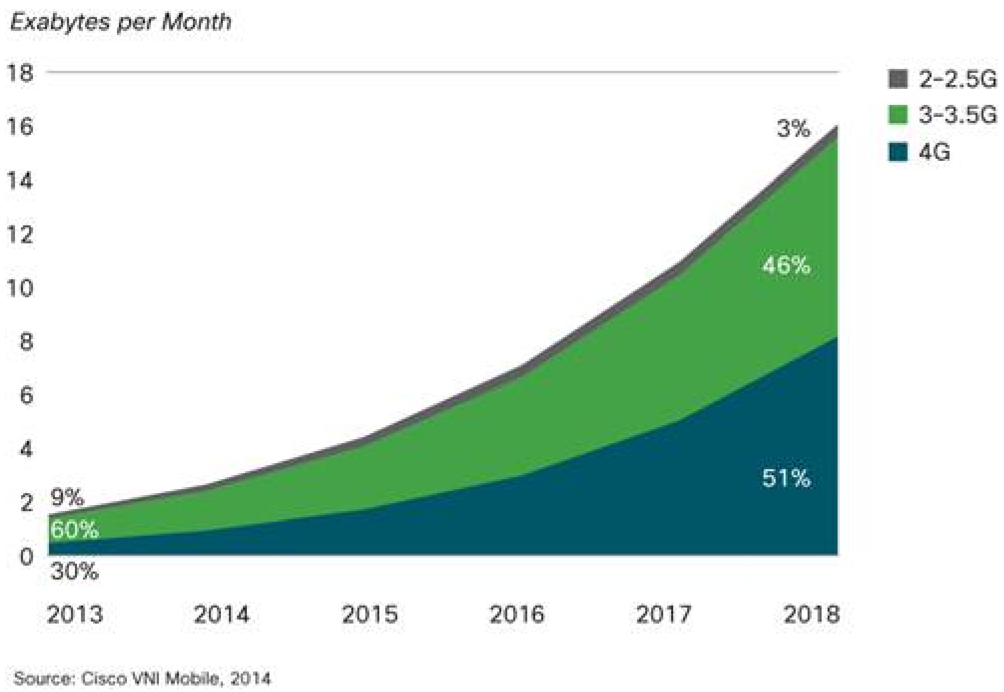


Figure 6 Mobile Internet traffic distribution prediction [3]

0.3.1.3 Applications

The traffic generated by various applications does not only change due to the increased usage of the specific service, but also due to the more demanding content. Therefore although the usage percentages may change, the actual network requirements by each type of application may be quite different. In the Fig. 7 it is obvious that the video on demand will overwhelm the traffic, along with the surveillance videos' flows. File sharing will halve its percentage, but it will keep actually the same amount of traffic. Web and general data traffic will increase but not significantly, over the next years.

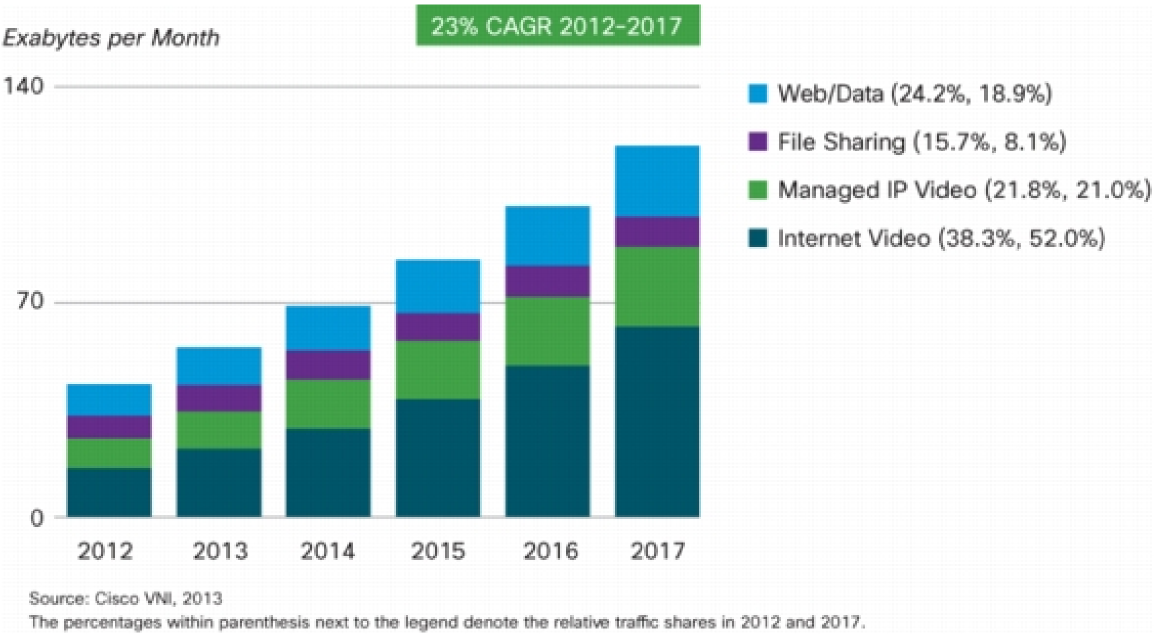


Figure 7 Future trend of the Interenet's traffic distribution [4]

0.3.1.4 Machine-to-Machine

The category of M2M communications has never been taken into serious consideration, but has a significant boost the last years that will continue to evolve. Today there are 300 millions M2M connections, mainly using 2G networks, but in four years it is estimated that the connections will increase to 2 billions utilizing mostly 3G (Fig. 8).

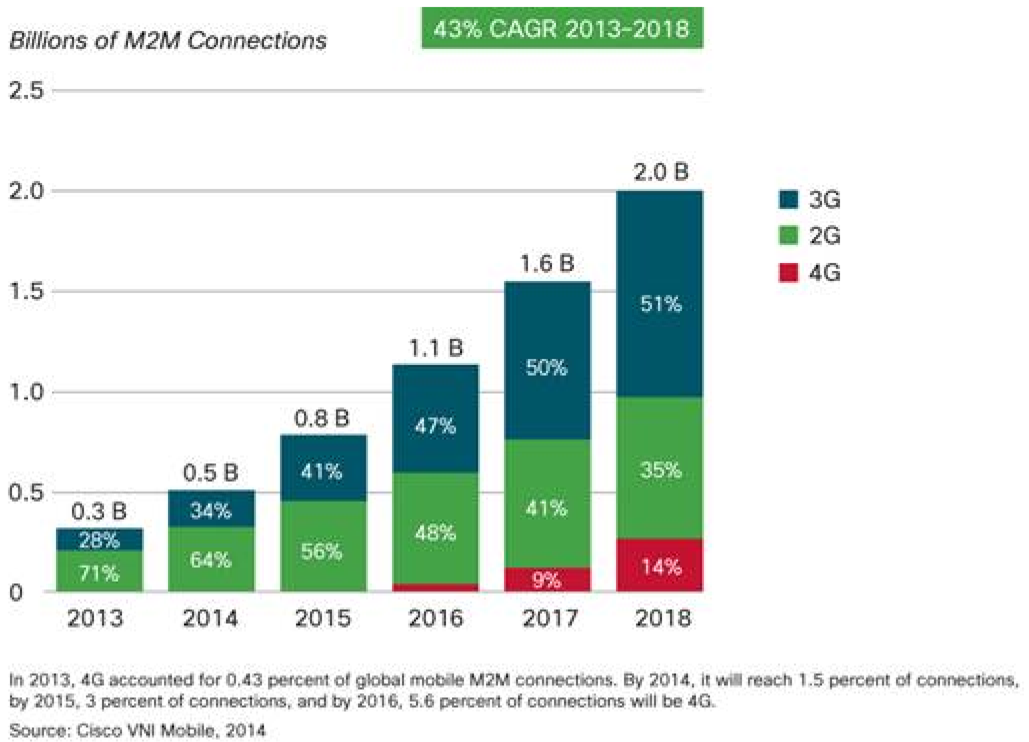


Figure 8 Machine-to-Machine connections on 2G,3G & 4 G mobile networks [3]

0.3.2 Broadband access service trends

The traffic allocation of the contemporary North American broadband connections is clearly depicted in Fig. 9. There is a distinct increase in real-time streaming content requirement, which nowadays overwhelms the capacity of the networks. Next, P2P services that enable large files' sharing are responsible for the same amount of traffic as the web based services, consuming about 35% combined. The rest type of services are requiring significantly lower amounts of bandwidth.

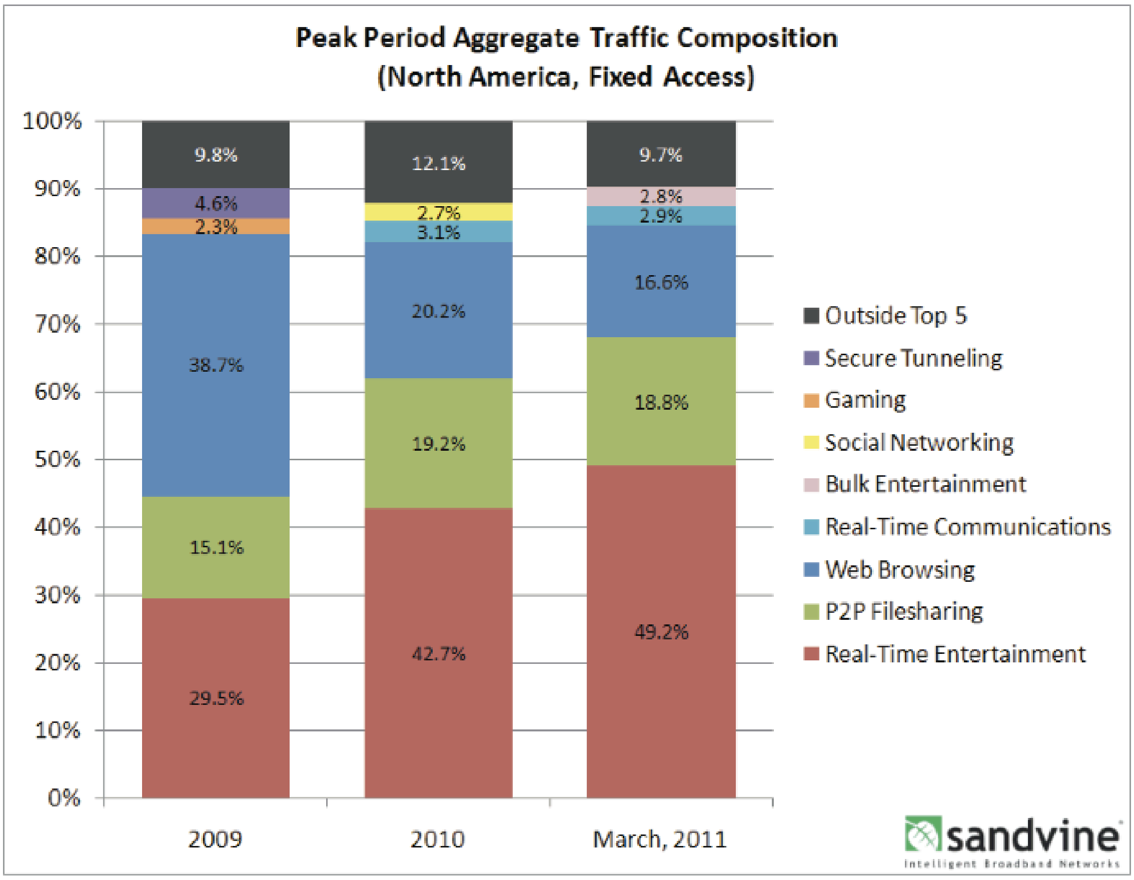


Figure 9 Traffic distribution per type of service [5]

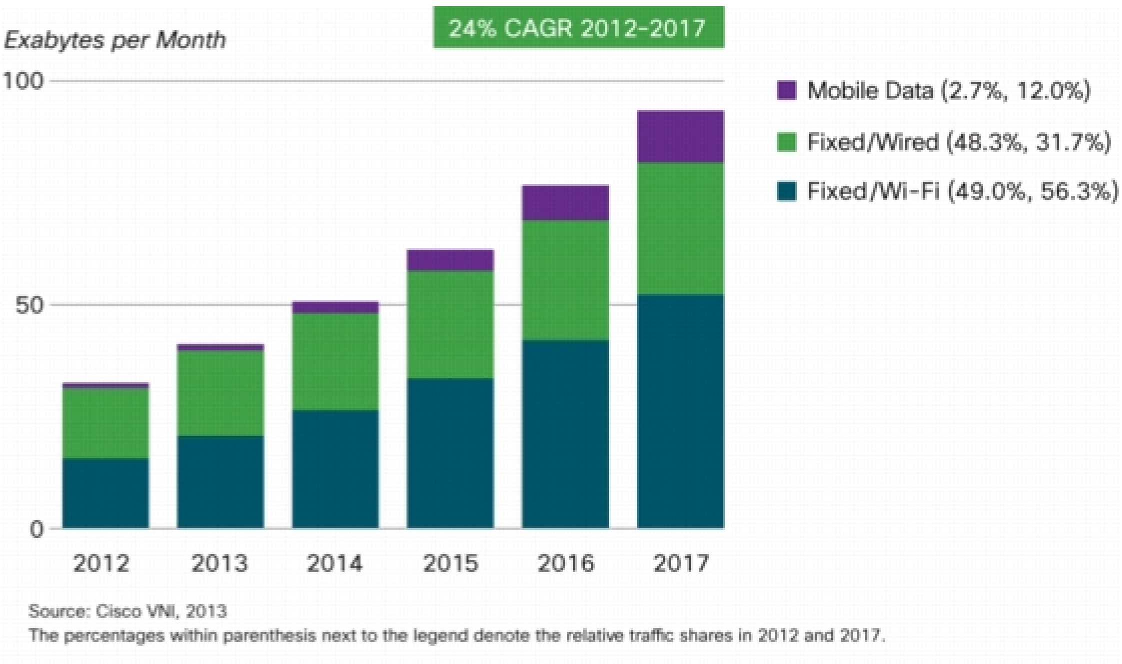


Figure 10 Wired, wireless and mobile data traffic distribution prediction [4]

0.3.3 Fixed-mobile convergence

In Fig. 10 the clear trend for increased data traffic through the use of wireless technologies over the traditional landlines is shown clearly. In three years the traffic over landlines will drop to the one third of the total, with dominating technology the Wi-Fi and mobile increasing to the significant 12%.

0.3.4 Traffic and application trends

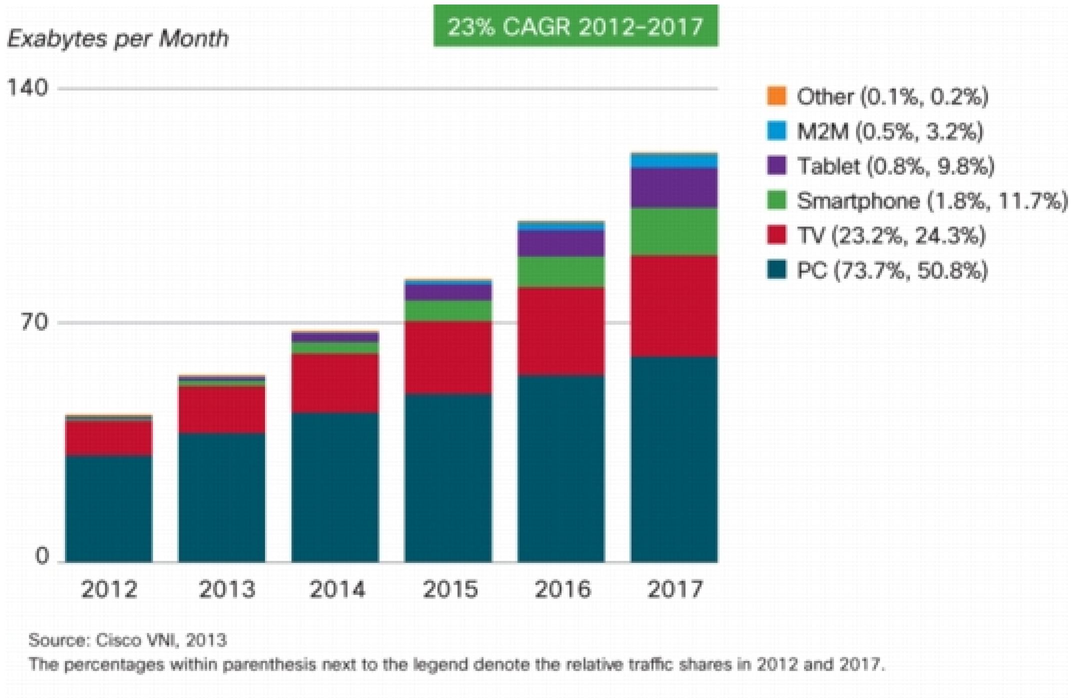


Figure 11 Prediction of the traffic distribution per type of device [4]

At the end of 2012, PCs produced the three quarters of the global Internet traffic (Fig. 11). In the next years the interconnected TV sets are going to take away one quarter of this traffic, and at the same time the smartphones and the tablets are going to account for over 20% of the total. The PC capabilities have already started to be "absorbed" in other, friendlier, mobile and slicker devices. Therefore it is expected that the Internet traffic will be rerouted to new type of devices as well.

A second significant observation is the usage of cloud services (Fig. 12), which already is dominating the generated traffic and its percentage will continue to rise in a slow pace for the following years.

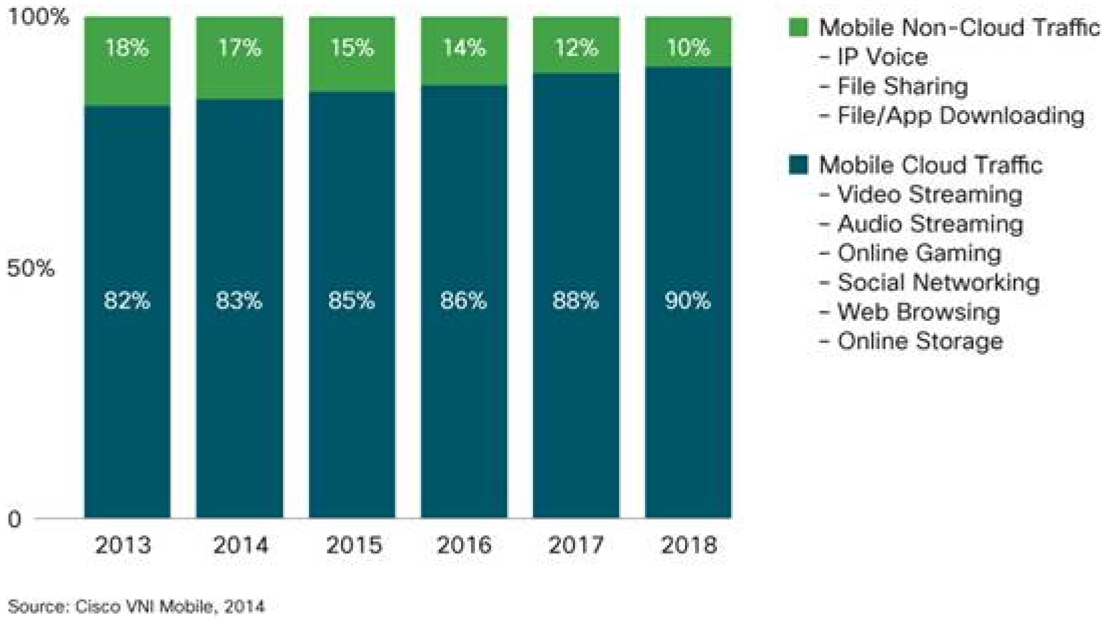


Figure 12 Mobile cloud vs. non-cloud traffic comparison [3]

0.3.5 Socio-economic trends

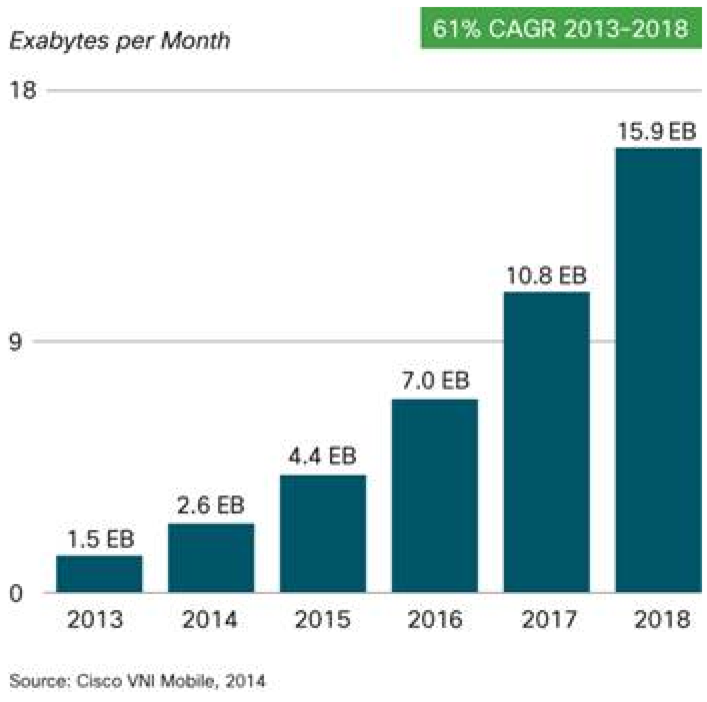


Figure 13 Total Internet traffic evolution prediction [3]

Currently the compound annual growth rate of the Internet traffic for the forthcoming years up to 2018 is predicted to be 61% (Fig 13). It is an extreme high rate that represents the investments that are going to be established in the telecommunications. The only way to support and sustain this rate of traffic volume growth is to build future-proof and sustainable infrastructures.

Another high growth rate trend is this of the connected wearable devices that is over 50% (Fig. 14). There is a relatively new type of devices that is going to play a significant role in the future through the M2M paradigm.

Figure 14 Connected wearables devices prediction [3]

0.3.6 Mobile lifestyle

Figure 15 depicts the mobile usage partitioning for the forthcoming years. It is quite obvious that the video streaming is dominating the chart. The other services that hold significant percentages are the web, audio streaming, M2M communication and file sharing. Nevertheless video streaming is predicted to account for almost the 70% of the mobile traffic in 2018.

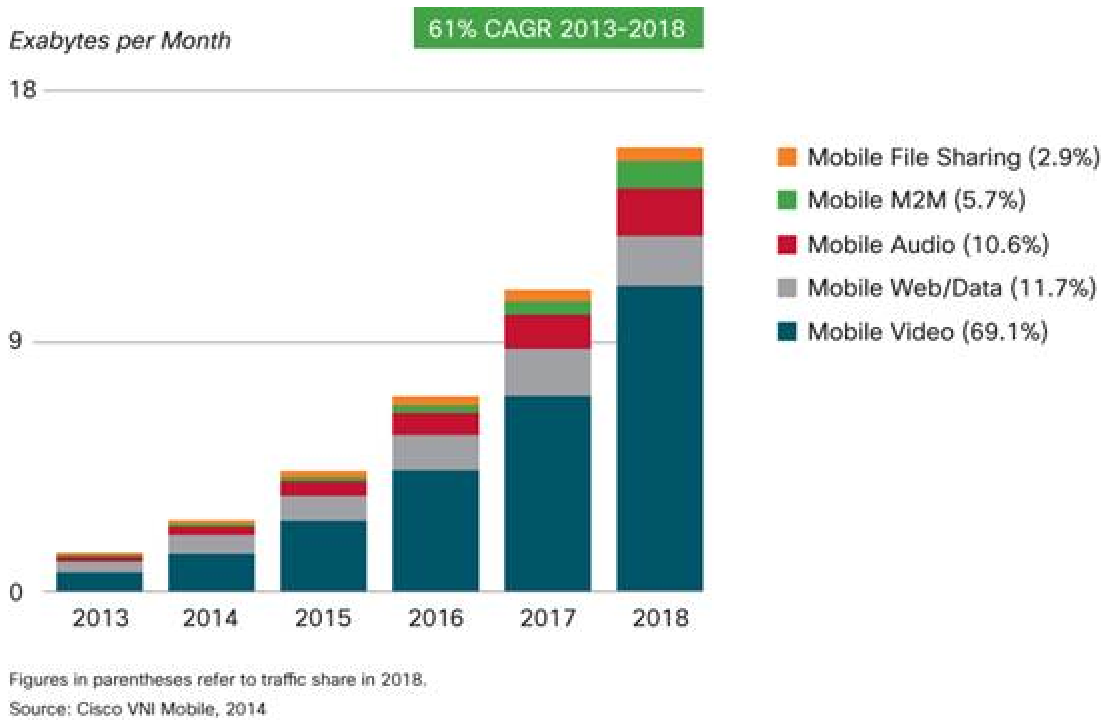


Figure 15 Mobile traffic partitioning prediction [3]

0.3.7 Digital divide

We showed previously that the per capita Internet traffic of North America is significantly higher than the other regions of the world. This digital inequality is going to balance in the next years, specially in the Asia-Pacific region, where the Internet penetration is rapidly expanding. In Fig. 16 it is clear that in 2 years the Asia-Pacific region will be responsible for more monthly Internet traffic than the rest of the world.

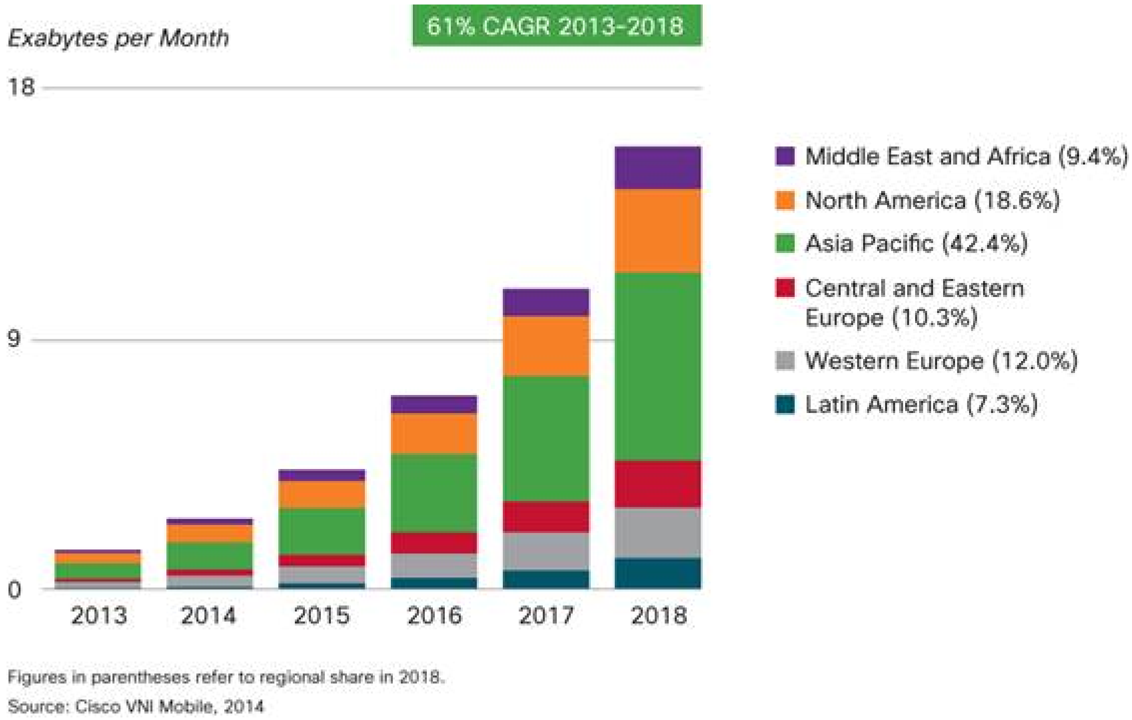
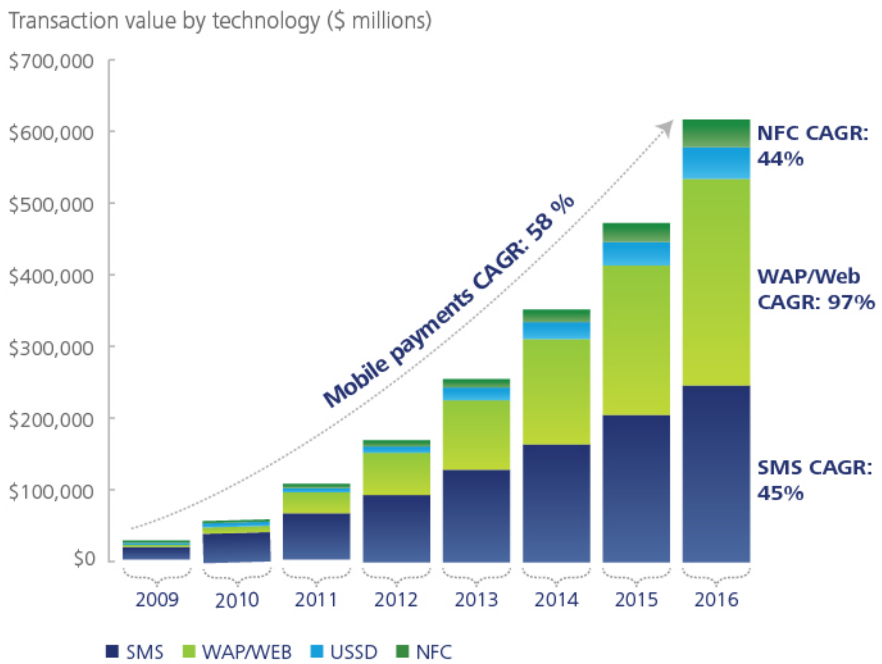


Figure 16 Per Month traffic volume per region [3]

0.3.8 Mobile e-Commerce

Mobile payments and e-commerce in general had a low volume of transaction even few years ago. But at the moment there is a trend for significant increase in the use of mobile payments that gives a prediction for 58% compound annual growth rate (CAGR). Technologies like NFC and iPhone Passbook push the mobile transactions even further due to the increased usability and easy integration to current widespread commercial transaction systems.



Source: Sandy Shen, *Forecast: Mobile payment, worldwide, 2009–2016*, Gartner, May 9, 2012; Deloitte analysis.

Note: Unstructured Supplementary Service Data (USSD)

Graphic: Deloitte University Press | DUPress.com

Figure 17 Mobile payments transaction value by technology [1]

1 Applications & Usage scenarios

1.1 Smart City

An urban-scale mesh network platform is the necessary infrastructure for a smart city environment monitoring and control. It should support a basic set of functionalities in order to provided the basic and more common services to the typical users. Below the typical usage scenarios and type of users are provided.

1.1.1 Services

The use cases of an urban-scale infrastructure are provided hereafter:

Monitoring:

- Pollution metrics, air/water pollutant concentrations
- Weather, temperature, wind, sunshine duration, rainfall intensity
- Indoor air quality, carbon monoxide, ozone, radon concentrations
- Electromagnetic fields levels, electric/magnetic fields limits observation
- Parking spaces availability/occupancy
- Traffic flow, congestion points, traffic lights control, traffic rerouting
- Noise levels, comfort levels
- Radiation levels, solar activity levels

Tracking:

- Vehicle Fleets (i.e. taxis, buses, rented bicycles)
- People with disabilities or health issues (i.e. Alzheimer, blindness), children, pets, criminals

Alert:

- Traffic congestion, accidents, road network problems
- Extreme weather phenomena (i.e. hurricanes, ice, very hot/cold conditions)
- Emergency situations (i.e. floods, tsunamis)
- Environmental hazards (i.e. chemical or radiation leakages, fires)
- Disasters or terrorists actions

Infotainment:

- Tourists' guidance and information retrieval, points of interest, advertisements
- Commuters, children, teenagers, gamers occupation
- News broadcast, authorities announcements
- Community information and public awareness actions

- Local interest information and updates

Video surveillance:

- Road traffic, control, management, accidents detection
- Public areas monitoring, suspicious behaviour tracking
- Gathering places overview and surveillance (i.e. airports, train, metro, busses stations, stadiums, theatres,)
- Restricted areas' intruders/trespassers detection

Smart meters monitoring:

- Electric energy, water, gas consumption real time monitoring and flow control
- Temperature, humidity, smoke/fire detectors remote monitoring and alarm
- Hazardous or polluting emissions flow monitoring

1.1.2 Users

The usage scenarios in a smart city environment, based on the user perspective and profile, are:

Mobile business user scenario:

A modern mobile business user who is always on the move, uses at least the smart phone to have continuous access to the email service, to the corporate data, receive news and information data regarding his/her profession, and perform conference calls. Thus the requirement of mobility is combined with parallel access to a variety of services that require high QoS, adequate bandwidth, high security and reliability.

Nomadic user scenario:

The nomadic business user is described by the intermediate stops for long periods of time in several places. The requirements during the stationary state are increased compared to the mobile user, especially in capacity and cost effectiveness.

Gaming user scenario:

The online gamer typically connects to an online special gaming platform and also competes and interacts with other players in real time action games. The capacity requirements are not high, but the delay and jitter requirements are strict, requiring a fixed QoS.

Fixed home user – leisure activity scenario:

The typical Internet user will connect to mail services, search the world wide web, perform e-commerce and e-government transactions, upload/download content, share files, use cloud services, stream video, and use teleconference and chat services. Elevated requirements are needed, high & symmetric throughput, differentiated QoS based on the service and cost effectiveness.

Fixed home user – entertainment activity scenario:

The aforementioned fixed home user, but with subscriptions to video and audio streaming services, either video/audio on demand or real-time broadcasts. Requires increased downlink rates, predictable QoS and cost effective service.

Tourist / attraction visitor scenario:

A visitor or tourist uses his mobile device in order to navigate and receive information related to his/hers location. The information may include multimedia content, advertisements, points of interest, public transportation, etc. Positioning information is needed, high percentage of coverage, easy and cost effective access.

Video surveillance / premises monitoring scenario:

A typical surveillance/monitoring service through the Internet for a small home to a large building. This kind of service requires multiple real-time video streams, environmental monitoring data and sensors alerts, as well as remote triggering of devices and events. High uplink and downlink bandwidth is required, along with minimum downtime.

Mobile typical user scenario:

A typical smart device owner, uses constantly the online services of social networking, updates statuses, sends/receive short messages, add/retrieves multimedia content, performs purchases of goods and services with the use of his/hers device, and uses the telephone service a lot. Typically low delay, adequate bandwidth, high coverage, energy and cost efficiency are required.

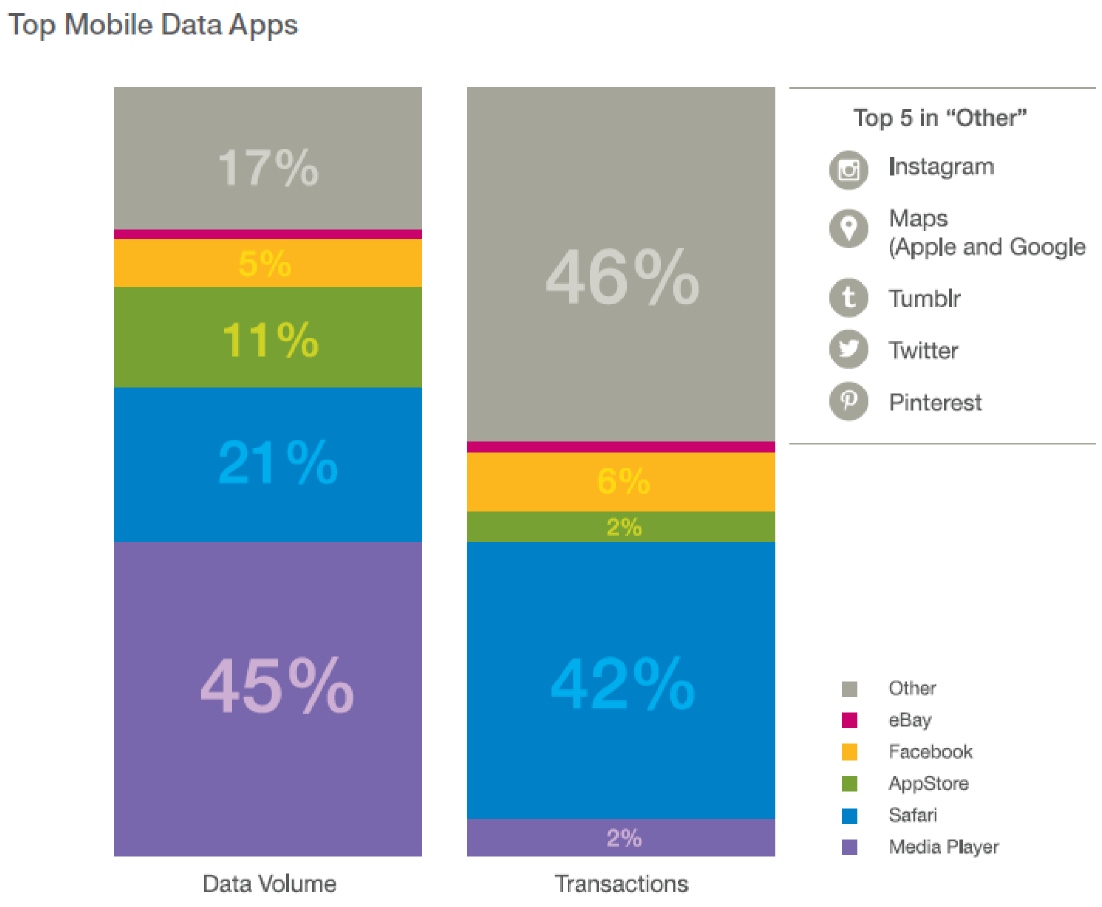


Figure 18 Top mobile applications for 2013 [6]

1.2 Emergency

In case of emergency communications are vital, but at the same time infrastructures are subjected to high load and in many cases physical damages. Catastrophic events i.e. earthquakes, fires, tsunamis, hurricanes, may destroy large part of the telecommunication infrastructures. Typical networks are not designed to cope with major failures and large area destructions. Moreover, high traffic loading is observed during these kinds of events due to the emergency calls, but also social contact. Terrorists' actions are another kind of incidents that may disable a wide range of telecommunication networks. The network itself may be targeted directly and even in logical level or by physical damage of the infrastructure. Extended failure of infrastructure components caused intentionally or unintentionally may disable the whole network and eliminate the communication capabilities.

Further than the susceptibility of the network in case of emergency, the network can play a significant role in identifying and mitigating an emergency situation. Monitoring, data collection and process by specially deployed networks can provide early warning for hazardous circumstances. Proper alarms through the network may prove to be invaluable and life saving. After an incident the rapid deployment of a communication system to be used by the rescuers and emergency teams, and if possible by the public, is of very high importance. Significant role to the successful deployment is the application service migration to the emergency deployed infrastructure with a transparent and efficient way.

1.2.1 Services

The use cases of an emergency infrastructure described here are:

First responders' interconnectivity

- VHF/UHF radio broadcast and relay service
- Private channels for direct personnel communication
- Inter- and intra-group communication

Emergency telephone number call

- Need for medical or other form of assistance
- Report an emergency incident
- Contact the authorities
- Get vital information

Information supply and public address

- Broadcasting of emergency messages
- Use of special portals or social networking services
- Multicast of public address audio/video streams

Monitoring

- Disaster areas
- Emergency units fleet
- Rescuers
- Operations
- People gathering places
- Environmental metrics

1.2.2 Users

The usage scenarios in case of an emergency, based on the user perspective and profile, are the following:

First responders/rescuers scenario:

The most common telecommunication requirement for the first responders is the use of VHF/UHF radios for the intra-team voice communication. Connectivity between teams in order to be able to coordinate more effectively and location information of the personnel concentrated in a control point are of high value too. More modern procedures also require the use of real-time streaming video, audio, or sensor data (i.e. vital signs), real-time remote control of robots, and download of imaging. Therefore, special telecommunication technology is required, high QoS with low delay and high bandwidth requirements, and high resilience in particular.

General public scenario:

The general public usually communicates with the telephone emergency numbers in order to contact the first responders or the authorities, seeks for real-time broadcasts or news-feeds to be informed, updates statuses in social networking services, and searches information regarding incident handling. In this scenario high bandwidth, multicast video streaming is required, high telephone service availability and QoS, and non-blocking high user-acceptance ratio resilience.

Local authorities scenario:

The local authorities need the most possible data flow from the incident area, multiple video/audio streams, numerous sensors measurements, location information of personnel and fleets, weather conditions and forecast, high voice communication availability. Thus there is need for very high downlink bandwidth for streaming purposes, high resilience and availability, differentiated QoS with low packet loss.

1.3 Special Considerations

A contemporary network deployment should also be structured with upgradability in mind. Investments in infrastructure are quite large and returns tale a long period of time, therefore installations that prove to be future proof are always more appealing. In order to be future proof a network needs to be both expandable and future standards aware.

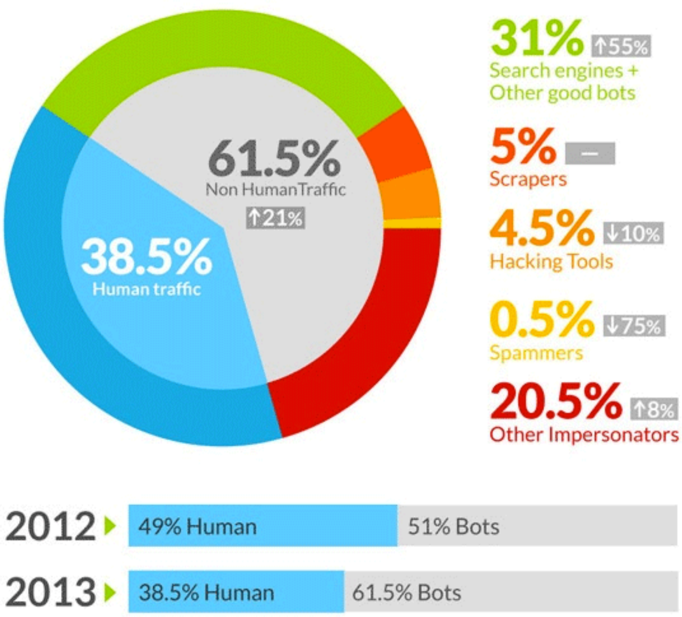


Figure 19 Human generated vs. non-human traffic [7]

But further than the typical user and services scenarios, there is also a very large percentage of network traffic that the infrastructure has to handle that is not based on real humans' activity (Fig. 18). Special software that searches and exploits the network is constantly increasing its traffic that has at the moment overtaken the traffic produced by humans. Although search engines and similar services produce most of this machine-generated traffic, there is a large percentage of traffic of malicious origin. This malicious load has a severe economical and waste of resources impact. On the other hand there is automated traffic generation that is welcome, but it may be handled with less priority and in a more energy efficient way, without significant impact on the service performance.

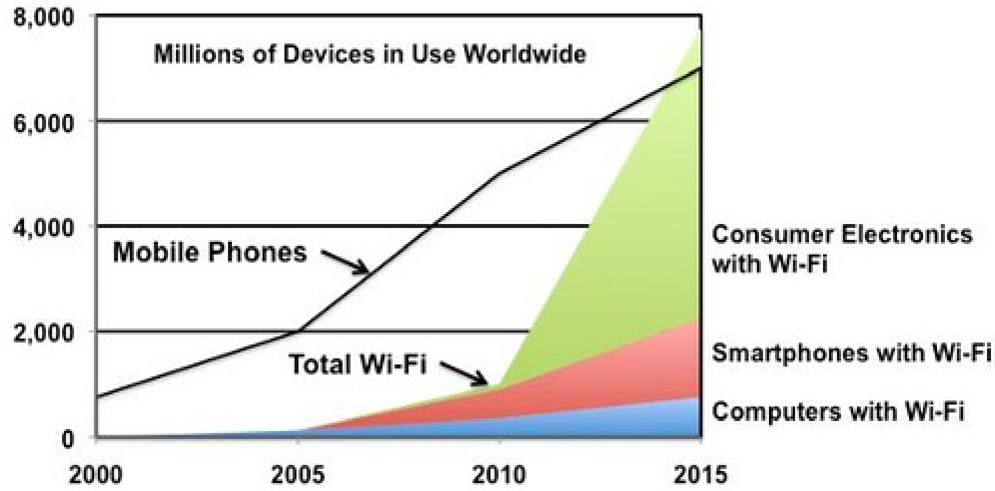


Figure 20 Wi-Fi penetration in the consumer electronics [8]

One final remark is that the IEEE 802.11 standard has overwhelmed the world of consumer electronics. It is the main technology used for most devices' connectivity and in the near future the Wi-Fi equipped devices will surpass the number of mobile phones, establishing the 802.11 as the dominating wireless technology (Fig. 19). Therefore there will be an excess demand in 802.11 wireless connections, and access points' coverage and availability, especially for stationary usage.

2 Requirements

The actual requirements, based on the type of service or application to be supported, are provided in Table 3. They are given in detail the downlink and uplink capacity requirements, the delay and jitter restrictions and the loss ratio acceptability [9]. Furthermore a description of guidelines for the support of various parameters of the network is provided as well.

Table 3 Requirements per type of service/application

Services/ Applications	Downlink /Uplink traffic ratio	Downlink speed	Uplink speed	Interactive	Performance parameters			Transmission mode
					One-way delay	Jitter	Loss ratio	
Basic Internet Services								
Web browsing	>>1	>500 kbps	4-25 kbps	Yes	<2s/page (acceptable <4s/page)		0%	Unicast
Email	1	>500 kbps	>500 kbps	No	<2s (acceptable <4s)		0%	Unicast
File transfer	>>1	>1Mbps	4-25 kbps	Yes	<15s (acceptable <60s)		0%	Unicast
Telnet	1	4-25 kbps	4-25 kbps	Yes	<250 ms		0%	Unicast
Conversational Services								
VoIP, tele-conferencing	1	30-80 kbps	30-80 kbps	Yes	< 150ms (limit <400ms)	<1ms	<3%	Unicast/ multicast
Video-telephony/ video-conferencing	1	32-384 kbps	32-384 kbps	Yes	< 150ms (limit <400ms)	<1ms	<1%	Unicast/ multicast
Instant messaging (IM)	1	4-25 kbps	4-25 kbps	Yes	<250 ms		0%	Unicast
Online chatting	1	4-25 kbps	4-25 kbps	Yes	<250 ms		0%	Unicast
Streaming Services								
IPTV	>>1	1-3 Mbps		No	<10s	<2ms	<1%	Broadcast
Mobile TV	>>1	28-512 kbps		No	<10s	<2ms	<1%	Broadcast
VoD (SD)	>>1	1-3 Mbps	<8 kbps	Yes	<10s	<2ms	<1%	Unicast
VoD (HD)	>>1	6-10 Mbps	<8 kbps	Yes	<10s	<2ms	<1%	Unicast
On-demand streaming media (MoD)	>>1	32-384 kbps	<8 kbps	Yes	<10s	<2ms	<1%	Unicast
Internet radio	>>1	16-320 kbps			<10s	<2ms	<1%	Broadcast
Video surveillance	>>1	32-1024 kbps	<8 kbps	Yes	<2s	<2ms	<1%	Unicast
Interactive Services								
Interactive gaming	1	4-25 kbps	4-25 kbps	Yes	<250ms		0%	Unicast
Real-time gaming	1	32-64 kbps	32-64 kbps	Yes	<50ms		0%	Unicast
Voice mail	1	30-50 kbps	4-25 kbps	Yes	<2s		<3%	Unicast
Collaborative working	>>1	>500 kbps	4-25 kbps	Yes	<2s/transact.		0%	Unicast
ASP services	>>1	>500 kbps	4-25 kbps	Yes	<2s/transact.		0%	Unicast
E-commerce	>>1	>500 kbps	4-25 kbps	Yes	<2s/transact.		0%	Unicast
Control of remote devices	1	<28 kbps	<28 kbps	Yes	<10s		0%	Unicast
Multimedia Sharing								
Peer-to-peer file sharing	1	>500 kbps	>500 kbps	Yes	<15s (acceptable <60s)		0%	Unicast
User-created	<1	32-64 kbps	>500	Yes	<2s/upload		0%	Unicast

content sharing			kbps					
Context-based Information Services								
Location-based multimedia broadcast	>>1	32-384 kbps		No	<10s		<1%	Broadcast
Location-based interactive multimedia	>>1	32-384 kbps	<8 kbps	Yes	<10s			Unicast
Location-based on demand services	>>1	32-384 kbps	<8 kbps	Yes	<10s		<1%	Unicast
Alert/notification, advertisement services	>>1	<28 kbps		No	<10s		0%	Multicast
Presence-based applications	>>1	<28 kbps	<28 kbps	Yes	<10s		0%	Unicast
Personalized content	>>1	32-64 kbps	<8 kbps	Yes			0%	Unicast

2.1 Capacity

One of the major resources that need to be controlled and used efficiently is the capacity. Unfortunately, capacity in mesh networks is a resource that is highly dependable of the network state and the traffic conditions. Therefore the distribution of the traffic over the available network resources defines the actual utilization of the theoretical maximum available. An evenly distributed capacity that balances the requirements to all available resources is the most robust solution, because it avoids the typical starvation condition of the shortest-path routing. In a typical network topology there is an increasing capacity demand from the edges to the core of the network, but in a mesh network this can be avoided through the utilization of the multiple available paths. Therefore traffic can be evenly distributed to multiple lower capacity paths without the requirement of fat pipes in the core of the network. This way the network is more resilient and provides faster and more precise adaptation to any capacity need change, without wasting resources. Statistically the higher capacity requirements are in the egress/ingress concentration points of the network, which also pushes the demand for feeding these points with large capacity backbone connections. On the other hand a more distributed scheme would require more points of less capacity, that are geographically dispersed, thus it provides better resilience avoiding single point of failure and congestion escalation problems. The distributed scheme applied on mesh networks provides unmatched scalability capabilities, that offer progressive and diffused capacity upgrades.

2.2 Quality of service

There are many applications where quality of service is necessary in order to perform adequately; multimedia, interactive, remote control, VoIP, etc. Two are the main attributes that need to be controllable: the delay and the capacity. Further than these, the packet loss/discard and jitter are also important factors of the QoS. In Fig 20 for example the correlation of packet loss duration against video impairments duration for various MPEG2 encoding rates is depicted. It is clear that in the case of MPEG2 video the visual problems last longer than the actual packet loss problem, an example that presents the careful provisioning needed.

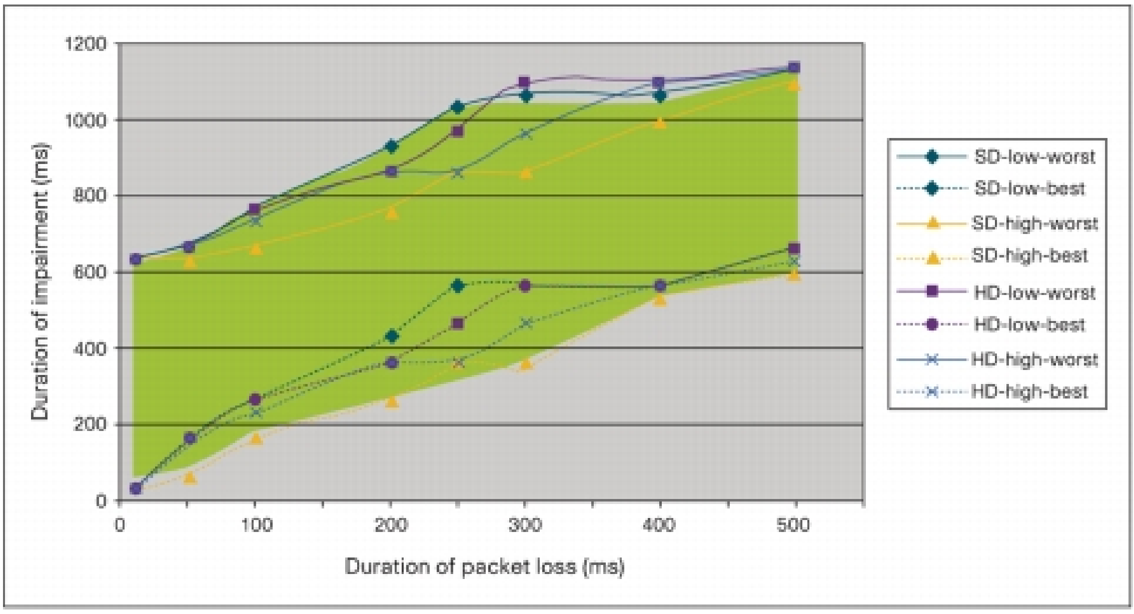


Figure 21 MPEG2 stream visual impairments duration vs. packet loss duration [10]

There is one major issue arising from the usage of virtualization, where service overlays are considered. The lack of cross-visibility between the logical overlays and the actual physical network, leads to performance and management issues. The QoS setup should somehow take into account the real, underlying, obfuscated by the encapsulation network infrastructure and provide the mechanisms for combinational setup of diverse and alienated networks.

2.3 Energy

Energy consumption is a key factor element both for economical but also sustainability reasons. Especially in emergencies where the availability of the energy sources cannot be guaranteed, the use of backup power and the minimization of energy requirements are essential. Therefore, the use of renewable energy sources can provide a solution, but it also requires the use of batteries for the storage of the produced energy excess, as the flow of energy is not continuous but interruptible. Consequently, the use of renewable sources, requires the proper power and energy requirements planning, and urges the utilization of power efficient techniques.

Moreover, this local generation of energy leads to a distributed system of multiple energy sources, with a non-conventional energy generation pattern. These local energy sources could be combined in a smart grid, providing high redundancy and failover capabilities. As a result, proper load shedding and ahead planning must be considered, minimizing the blackout events in the communication infrastructure. Smart energy distribution in a way that there are no holes in the coverage is preferable over increased capacity in smaller areas. The best way to achieve this goal is the interoperability of the nodes and the predictability of the geographical coverage and traffic.

2.4 Resilience

Resilience is a feature that the mesh architecture partially covers it by design. Further than the inherited durability and flexibility, techniques that are more active are required in order to maximize the performance. Physical disasters or terrorism actions may destroy or disable a very large portion of the network or untether it from the Internet. Moreover, the network does not handle cases of congestion automatically for example. Interference may be effectively addressed within the network nodes by a collective system, but in case of external interferes a more sophisticated approach is needed.

Low capacity but long distance technologies provide the Internet connectivity in case of landlines failure. Two-way satellite connections are the ultimate backup solution as the satellite networks are the less probable to be affected by any on-Earth condition.

Delay-tolerant networking techniques will provide the mechanisms to adapt into the increased delays imposed by the aforementioned problematic circumstances. Moreover an opportunistic communication scheme can be applied in case of an emergency, where all the available resources are detected and used accordingly.

Survivability is the desired feature, even with lower performance; therefore the lack of instantaneous end-to-end path should be expectable and managed through delay-tolerant mechanisms providing persistence even under harsh conditions.

2.5 Multi-connectivity

The vast diversity of networking standards and protocols used in a smart city or in an emergency scenario, necessitate strong multi-connectivity capabilities. The first step is to support concurrently as many standards as possible, but this directly introduces problems that involve interference avoidance, spectrum sharing and channel selection. This set of required mechanisms that are strongly related, focus on the physical layer properties and functionalities. Therefore a cooperative mechanism between the different standards, enabling the direct exchange of information, will improve the physical layer performance at least of the intercommunicating nodes. On the other hand, the parallel existence of multiple heterogeneous networks cannot always satisfy the cooperation, therefore spectrum sensing techniques and interference mitigation algorithms are essential.

The best practice is to provide a series of cognitive capabilities and mechanisms targeted to the alleviation of the physical layer issues. Furthermore, the multiple standards support requires the use of a cross-layer design concept, enabling the routing to be part of the physical layer's performance optimization. The routing through a diverse set of standards and protocols imposes the use of non-trivial algorithms, and further cooperation schemes in the higher networking layers are required.

2.6 Management

The complexity of a WMN requires the utilization of a robust management system in order to be supervised, organized and controlled properly with minimum effort. The primary goals of a management tool are the efficient, effortless and comprehensive planning, configuring, monitoring, reporting and alarm triggering, with the minimum required human interaction. Visualization of the network's performance and status data is a key element, mapping the information of the RF coverage and interference, wireless performance and capacity, node, user and rogue device location, malfunction and security alerts location. Further than the user interface the management system should provide several of the mechanisms that contribute to the network's reliability, resilience, security and performance. The former are achieved by assisting the network design during the deployment and the continuous real-time monitoring and statistics processing. The services-centric approach, that is being employed the last years, provides an even better performance in the areas of mobility, voice, location, security and resources allocation. On the other hand virtualization hides the complexity of the underlying network, but at the same time requires an even more advanced management system. Last the heterogeneity of the network combined with the geographically dispersed devices, add extra challenges to the management of the system, where mechanisms for real-time configuration and service deployment are essential.

Therefore the centralized management architecture should comprise two sets of components: a) one set for identifying the type and capabilities of the network devices, and establishing a specialized communication with each device or device type, and b) one for providing configuration, provisioning, management and monitoring functions. The communication with such devices in many cases cannot be direct and thus will require the intermediation of a technology gateway to act as a supervisor and as an abstraction layer for the sensor network. This will be a more general approach that will open the possibility of applying the routing, management and monitoring approaches to a wide range of network devices. A more general and abstract view of the network will be provided in order to consider the network as a general topology with specific characteristics, thus going beyond the distinction between the specific devices' technologies. This will grant the possibility of implementing advanced services on top of the network by just considering capabilities and not the single technologies. A high level, service-dependent reconfiguration of the network will trigger lower level and technology specific configuration modifications. Finally, monitoring should be further developed, by adding more service-oriented monitoring functions that will cover different technologies, in order to provide a higher-level view of the network as a whole.

2.7 Mobility

Mobility is the key characteristic of most modern computational devices (Fig. 22). In order to enable seamless mobility in a network, several components and layers are needed to coordinate and participate in the roaming scheme. Unfortunately, most standards do not provide the best possible provisioning for this feature; therefore, special treatment should be applied. Traffic prediction may compensate some of the problems, but there is always the possibility of unpredictable traffic patterns, therefore reservation of resources is required. Provisioning of QoS, and even over-provisioning of some resources are QoE enabling aspects. Mobility may be assisted by location prediction via positioning techniques in respect to the traffic prediction patterns build assistance. Further, the increased occurrence of short lifetime connections due to mobility requires the awareness in terms of caching, connections persistence, and maximum users limitations.

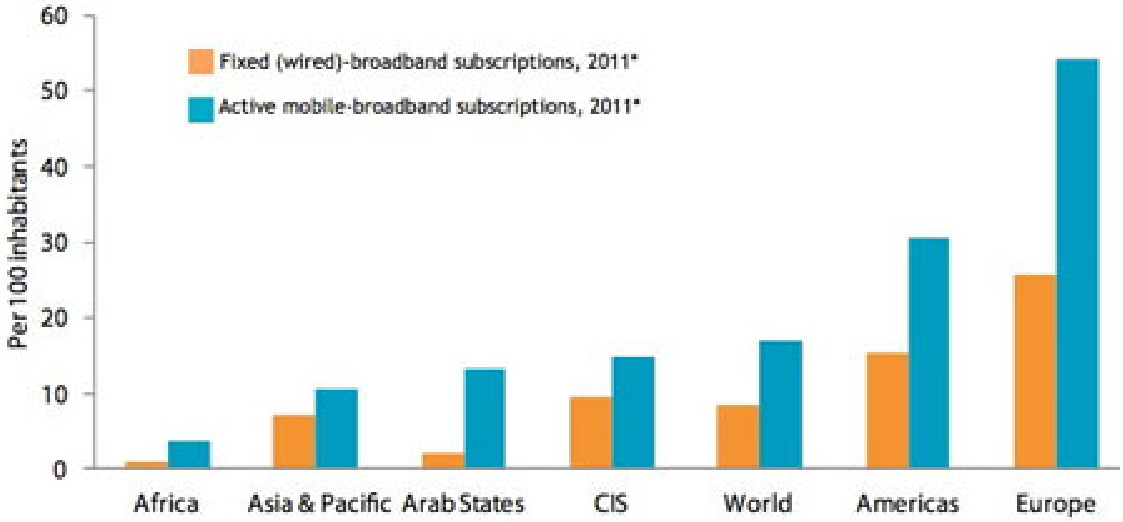


Figure 22 Wired vs. mobile subscriptions in 2011 [11]

2.8 Virtualization

Virtualization is one of the key-role functionalities in a contemporary mesh network. It relaxes the requirements for a complex, mesh-aware application design, as it optimizes the usage of the underlying network at the same time. Virtualization provides the capability of differentiation in a logic level, thus it offers the same view of the network for the upper layers. Therefore, the requirements for the development of the applications are relaxed and there is a future-proof assurance.

Virtualization can provide abstraction of multiple tiers; physical layer, path routing, service type, capacity, QoS parameters (Fig. 23). There are types of virtualization that are applicable in the lower networking layers and at the same time the service overlay concept requires the vertical deployment of the virtualization system.

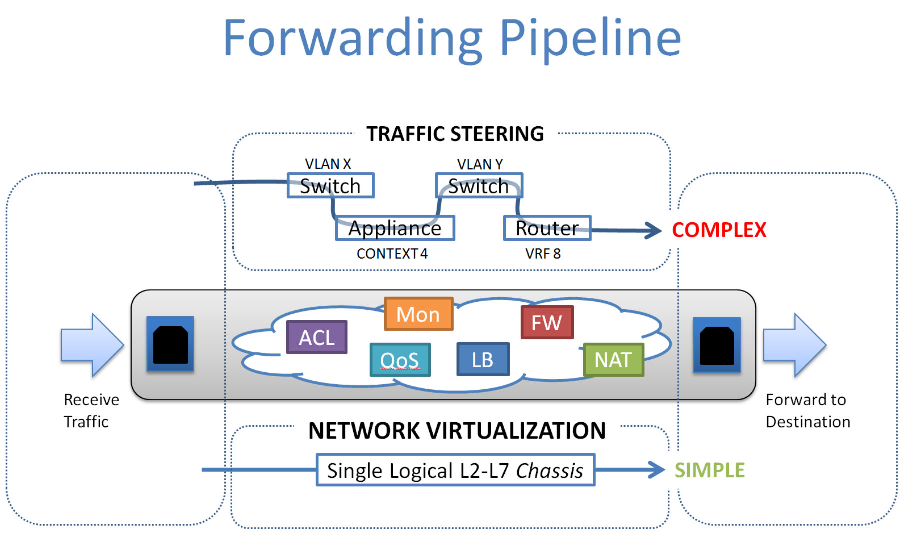


Figure 23 Network virtualization abstraction [12]

The overlays through the use of virtualization enable the service centric approach and the community centric model as well. By caching the actual underlying network structure, the upper layers may be provided with an exact matching topology offering the best possible performance and minimum management effort at the same time. Therefore, the physical mesh substrate may be shared and divided using virtualized routing overlays on top of it. The automatic construction of this kind of overlays provides the dynamic network virtualization, a highly desirable feature. The physical resources may be controlled, aggregated and re-allocated dynamically, exchanging resources between the underutilized and the over-utilized service overlays, thus balancing the network and offering unlimited flexibility (Fig. 24). Moreover, it can be combined with the service discovery feature, enabling the transparent mapping of services to overlays through an automatic, on-demand construction of virtualized routing layers. Resources discovery, modelling and allocation become an effortless task that is masked by the virtualization. Further than the abstraction it also provides the capability of using cross-layer incentive mechanisms that do not need to be specifically designed for a certain type of network, infrastructure or technology, but are able to adapt in any current or future prototype.

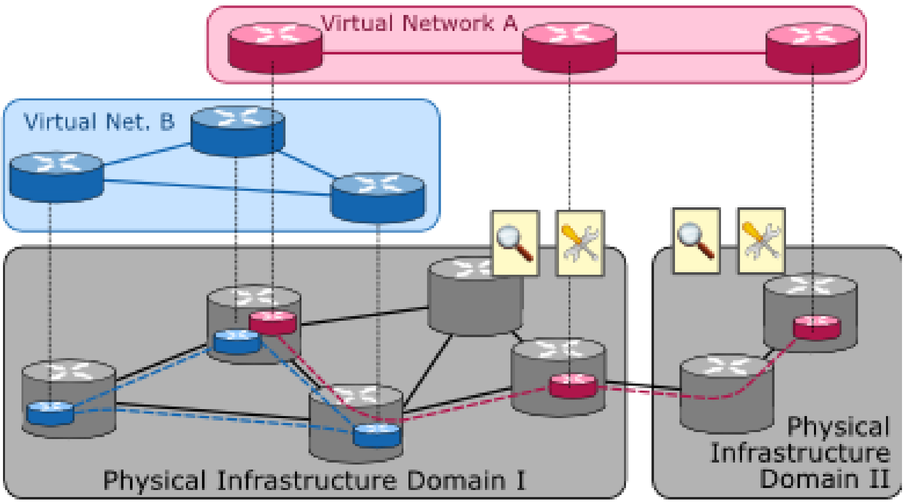


Figure 24 Virtualization example [13]

3 Glossary of Terms

3GPP	Third Generation Partnership Project
AC	Advisory Committee
ANSI	American National Standards Institute
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditure
CRM	Customer Relationship Management
EDGE	Enhanced Data Rates for GSM Evolution
eNodeB	Evolved Node B
EPON	Ethernet passive optical network
ERP	Enterprise Resource Planning
ETSI	European Telecommunications Institute
FCC	Federal Communications Commission
FTTx	Fiber to the x
FORTH	Foundation for Research and technology
FP7	Seventh Framework Programme
GHz	Gigahertz
GSM	Global System for Mobile communications
HSPA	High Speed Packet Access
ICT	Information and Communication Technologies
IEEE	Institute of Electrical and Electronic Engineers
IMT	International Mobile Telecommunications
IP	Internet Protocol
IPR	Intellectual Property Rights
IR	Incremental Redundancy
ISP	Internet Service Provider
ITU	International Telecommunications Union
LiU	Linköping University
LTE	Long Term Evolution
MAC	Medium Access Control
MHz	Megahertz
MPEG	Moving Picture Experts Group
PHY	Physical Layer
PMB	Project Management Board
PMB	Project Management Board
ProM	Project Manager
QoS	Quality of service
RTD	Research and Technological Development
SiC	Scientist in Charge
ToK	Transfer of Knowledge
UHF	Ultra -high frequency
ULUND	Lund University
UMTS	Universal Mobile Telecommunications System
VHF	Very high frequency

VoIP	Voice over Internet Protocol
Wi-Fi	Wireless Fidelity (IEEE 802.11)
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WMN	Wireless Mesh Network
WP	Work Package
WPL	WP Leader

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