OUTLOOK

Visions and research directions for the Wireless World

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Requirements and vision for

NG-Wireless
Work Group 3 White Paper

Requirements and vision for NG-Wireless

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0. Abbreviation

For the purposes of the present document the following abbreviations apply:

3D  Three Dimensional
BS  Base Station
BSS  Base Station Subsystem
CAPEX  Capital Expenditure
CDMA  Code Division Multiple Access
CN  Core Network
DVB  Digital Video Broadcasting
DVD  Digital Versatile Disc
EPS  Evolved Packet System
FDD  Frequency Division Duplexing
GSM  Global System for Mobile Communication
GW  Gateway
HD  High Definition
HSPA  High Speed Packet Access
ISD  Inter-Site Distance
LDPC  Low Density Parity Check
LLC  Logical Link Control
LTE  Long Term Evolution
M2M  Machine to Machine
MAC  Medium Access Control
MIMO  Multiple-Input Multiple-Output
NG-Wireless  Next Generation Wireless
OPEX  Operational Expenditure
PDN  Packet Data Network
QoS  Quality of Service
RAN  Radio Access Network
RAT  Radio Access Technology
RFID  Radio Frequency Identification
RLC  Radio Link Control
RRM  Radio Resource Management
RRU  Remote Radio Unit
SAE  System Architecture Evolution
SON  Self-organizing network
TCP  Transmission Control Protocol
TDD  Time Division Duplexing
UDP  User Datagram Protocol
USIM  User Service Identity Module
VoIP  Voice over Internet Protocol
WDM  Wavelength-Division Multiplexing
WiFi  Wireless Fidelity
WXGA  Wide eXtended Graphics Array
1. Purpose

This document describes our common vision on next generation wireless systems (NG-Wireless). Its main purpose is to present the current trends in mobile networks, motivate the need for research in specific areas, introduce the potential for new business opportunities, and sketch out the research results that can increase network performance to a level that can efficiently handle the current growth expectations in terms of energy efficiency, capacity, throughput, and deployment. This document does not describe any specific solutions, but does list the key NG-Wireless features. In short, this document outlines a clear path to future networks over the next decade.

2. Scope

NG-Wireless focuses on proposing a future Internet Oriented wireless system for Year 2020 around. The research work of NG-Wireless mainly includes 3 phases.

Phase I: Requirements and vision

The Vision outlines some typical potential services supported in the NG-Wireless network. Key features of these potential services are emphatically analyzed. Requirements generalize the main functions and capabilities that NG-Wireless shall support to realize the vision, all the requirements are extracted from the analysis on potential service, environmental constraints, traffic model, etc.

Phase II: Network architecture

The network architecture of NG-Wireless will be defined in this phase based on the requirements specified in Phase I. Specific definitions on radio transmission technologies are out of scope.

Phase III: Potential key technologies

Some potential key technologies of NG-Wireless will be provided in Phase III.

This white paper focuses on Phase I.

3. Vision

As for the future, your task is not to foresee but to enable it.

~ Antoine De Saint-Exupéry

The vision for NG-Wireless is based on an architecture designed to address the needs of more diversified future telecommunication markets. NG-Wireless can inexpensively provide user-centric communications catering a multitude of services to end-users (and machines) with seamless mobility, application and session management, guaranteed QoS and throughput at an order of magnitude higher than the latest standardized technologies such as Long Term Evolution/System Architecture Evolution (LTE/SAE). At the core, NG-Wireless is a cognitive and energy-efficient architecture with a reduced number of functional nodes, which can easily provide scalability for control and payload independently, incorporate a variety of access technologies and offer mobility support agnostic of the wireless interfaces.

In order to address the anticipated growth in the number of terminals and traffic, NG-Wireless will introduce a novel radio access technology (NG-RAN) which will deliver 20 times more throughput than LTE-Advanced and can meet the Year 2020’s requirements, having 1000 times more throughput and 1000 times more traffic than Year 2010. In addition, the introduction of decentralized autonomous communications by ad hoc networking will help towards fulfilling such future requirements. In order to achieve such ambitious goals, NG-Wireless will be founded on five pillars:

i) Virtualization of network functionality (4.7) as well as of computation, communication, and storage resources in order to deliver cost-, spectral- and energy-efficient operation especially in multi-administrative domain environments

ii) Modularization through the separation of functionality into generic self-contained building blocks to support a variety of business models and regional specifics. In addition, the goal is to increase operation and management efficiency through building blocks that can be subject to high-level standardization and can be flexibly combined to address different market requirements. NG-Wireless will take into consideration the tussle between users, operators and service providers by focusing on (common) functionality that supports different solutions for similar requirements, e.g., depending on the regulatory and market environment. This approach shall avoid unnecessary fragmentation of functionality.
iii) Cognitive network operation at the core network and at the RAN, which considers multi-access connectivity and multi-path routing as the norm and can steer direct device communication based on the knowledge of the networks, the ability to perceive and (re)act depending on network conditions as well as learning from the actions taken.

iv) Content-oriented networking mechanisms which can deal with the vast increase in dissemination traffic and ease service provisioning and delivery by operators.

v) The deployment of autonomous decentralized wireless ad hoc networks in its several forms, i.e., mesh networks, mobile ad hoc networks, sensor networks and RFID networks, in order to provide novel applications and decentralize services from core infrastructures to location specific networks where applicable. Particularly, the introduction of machine-to-machine communications in future Internet will greatly benefit from such architecture. The decentralized nature of network service provisioning will enable users to have better QoS and ubiquitous access to current services. Besides ad hoc networking will enable the formation and deployment of novel services.

In this vision, operators equipped with smarter wireless access pipes and a cognitive, energy-efficient network core developed by vendors, will be able to facilitate the rolling out of services, which address a diverse set of user devices in a scalable manner and in a variety of network environments including much denser deployments. As the boundaries between fixed and mobile networks are torn down, and professionally managed infrastructure and privately owned networks deployed by users and communities can interwork seamlessly, new opportunities will arise. To this end, NG-Wireless is suitable both for traditional vertical operator deployments and is a key enabler for the establishment of new business actors based on horizontal functionality splits of the value chain. We claim that it will be impossible for operators to provide the same functionality by simply upgrading to already-standardized mobile broadband technologies. Instead, the NG-Wireless flexible architecture will provide the possibility to adapt functionality to address different market requirements without sacrificing end-user experience. The extension of the current core architecture with peripheral decentralized neighborhood ad hoc networks will help provide seamless and ubiquitous mobile broadband services access to end-users [50].

4. Service Description in 2020

The basic nature of communications is experiencing a sea change with a host of new services being created to support evolving user needs. Real-time low rate phone usage is in a decline. Asynchronous (non real-time) services such as email, multimedia texting and social networking are much more popular and dominating wireless internet use, making download and upload rates more symmetric. Synchronous real-time services such as 3D video and gaming are dominating over low rate voice. Many of the wireless applications are third party server driven solutions. It is possible that peer to peer applications will find increasing use. The need for reliable public safety and emergency services is increasing. Another attribute of emerging services is that they utilize a variety of information. For example, augmented reality utilizes location information, map information and user preferences.

Radio access has to support new services efficiently. Some of the design paradigms of radio access have to change, for example the support of a high bandwidth uplink. M2M traffic may experience protocol overload and excessive signaling with the current protocol format. For the most part, new services require changes to the layers above the physical layer.

Although it is possible that new applications with high throughput requirement such as 3D media, augmented reality and the Internet of Things will arise and become widespread, it is hard to make a prediction on this throughput requirement. A reasonable way to address this uncertainty in the future may be to leave a throughput margin in the system design. Some of the services and related aspects of changing services are discussed in the paragraphs below.

4.1 Pervasive High Definition (HD) Multimedia

HD Multimedia is expected to occupy over 80% traffic through the network in 2020. And as a dominant and killer application, HD Multimedia should be fully supported to be delivered over wireless network, in forms of unicast, anycast, multicast and broadcast. Most contents of HD multimedia in the wireless network may be in 1080i (25-30fps) or 720p (50-60fps) based on H.264 encoding standard which means that an average data rate of at least 6-8 Mbps is required.

For pervasive HD multimedia envisaged in 2020, users can use their mobile phone, laptop, wireless car equipment, etc. to enjoy and share the HD multimedia contents through wireless network at anytime and
anywhere. Most possibly Wide eXtended Graphics Array (WXGA) screen will be used by most wireless equipments and the screen resolution may at least reach 1280*720 pixels so that users can enjoy the HD multimedia in their wireless equipment comfortably.

Pervasive HD multimedia in the wireless network may require really high throughput in a region which is far beyond that can be supported by today’s cellular network.

4.2 Application Mobility

For many applications, in particular those with strong audio/visual contents, mobility between devices while maintaining session continuity promises to deliver a completely new user experience. Moreover, application mobility will enable operators to help attract and retain users for service providers.

A typical scenario involves a family leaving home for a car trip while the kids watch a streaming video. As the family gets in the car, the video continues exactly from the point that it was stopped when the family lefts the house. Here we have transfer of context, network access (from wired or fixed wireless broadband to mobile broadband along the highway) and application client software. It is important to highlight that transcoding as well as scalable video/audio technologies can play a key role in materializing this scenario. Next generation mobility management is also a key enabler while a cognitive core network can (re)direct the usage of resources. Finally, note that this scenario does not refer to Digital Video Broadcasting (DVB) or other broadcast technologies but personalized, value-added A/V services.

Application mobility may also refer to the ability to reach a person over different (traditional) service delivery channels. For example, a number of users may join a telephone conference using Voice over Internet Protocol (VoIP). Some of them, as part of the same team will use a conference room joining the call from a single device. Presence for each of the participants is monitored accurately but unlike today where we rely on voice confirmation only. People from the team may leave the conference room and automatically be dialed in via their mobile phone seamlessly. In this case, presence, ID management, and seamless connectivity are handled in the background without any user intervention.

Finally, application mobility may refer to the transfer of data and changing the execution environment for several user applications. For example, while in the home/office a user takes advantage of local and cloud-based computation and storage resources, but resorts to cloud resources on the go in order to save on energy and improve performance. The seamless management of application mobility in this case can deliver significant benefits for operators as users hang on to the service provided.

4.3 Personalized Services

Personalized services can automatically fit user’s surrounding environment, context, personal preference, equipments, network conditions etc. for better quality of user experience. Different users may have different requirements related to the QoS, charging, presence etc., even when using the same services. Personalized services can meet user’s personalization requirement and let users get what they need for what they pay.

Users can set the policy or rules in the network side to dynamically adapt to the network condition such as roaming, congestion, handover, etc. Information and services also need to become increasingly tailored to individual preferences to make the usage of services easier and the perception of the individual communication space richer in 2020. An extended personalization concept is needed that enables value networks (e.g., value chains) of contents providers, network providers, and service providers to offer personalized services to mobile individuals in a way that suits their needs, at a specific place and time. Investigations into benefits according to the user perception are necessary and needs to be considered in the design of personalized services and personalization supporting frameworks.

Sensors may be widely used in 2020, making it easy to obtain the environment information, such as location, weather, etc., as context to provide personalized services for different individuals. The services may automatically adapt themselves to changes in the environment. Users may be agnostic to the dynamical adaptation so that personalized services can provide better service experience.

The main issues behind personalization are:
- Environment perception
- How to represent personal preferences and environment information
- How to gain personal preferences from individuals (interactively or automated)
– Privacy & Security.

Such personalized services will include smart home services where users can use ad hoc networks in order to customize home environments using smart devices e.g., sensorized devices, as well as devices that have higher processing capabilities. Using such devices, users can customize the ambience of the house as well as automate and schedule household chores.

4.4 User-centric Communications

Users may have lots of wireless equipments in 2020, like handheld equipments, sensors, smart home equipments, office equipments, car equipments etc. The traditional device-oriented communication mode may not be well adapted to this single-user, multi-devices, multi-networks scenario. Communications in 2020 may be based on user identifiers so that users can be reached anytime and anywhere in any devices; Services can switch between devices smoothly so that users can always use services in the most suitable device. Network may support the routing mechanism, mobility management, security/privacy management etc. which are all based on user identifiers. Network may establish the common application exchange platform based on user identifier technology so that users can communicate without specific application communication platform.

The features user-centric communication can provide are:
– Sharing anytime, anywhere, with any devices
– Route information/services etc. to the most suitable device
– Seamlessly multi-device handover
– Secure/privacy assurance
– Mobility management.

4.5 Enhanced Internet

The Internet contains a lot of information that can be very useful to support users in real-world activities. Unfortunately, this information is currently very cumbersome to access and accessing the information disrupts the users' workflow.

The Internet may be enhanced with information-centric capability that integrates Internet services or information with real world seamlessly in 2020. The enhanced Internet would enable users to get digital information or services based on entities or events in the real world. Entities may be expressed as an identity of the information and events may act as a trigger or context. Meanwhile, applications in the enhanced Internet could provide real-world interfaces to access information and services related to physical entities like objects, people, and places. For example, instead of searching the Web to get introduction information about a certain landscape during sightseeing, links of all related services or information would pop up immediately once one enters the scope or takes a picture with his/her camera. The information can then be presented in any desired way, e.g., via camera, via the cell phone display, or via augmented reality glasses. Besides requesting information about entities, the user could also execute entity-related operations. For example, a tourist can book a room when he/she points his/her camera to a hotel. Additionally, 3D internet may become very popular in 2020 since 3D experiences may be very similar to the real world so that people may be more likely to choose to stay home and use 3D services in the internet to save time and money. The most popular 3D services in internet may include 3D travel, 3D game, 3D shopping, 3D remote medical care etc. The enhanced Internet can benefit users in many ways and will dramatically change the life style in the future.

The main issues behind enhanced internet are:
– How to represent entities or events in the real world
– How to integrate real world with internet services seamlessly.

4.6 Machine-to-machine Communications Network

Machine-to-machine communications are a flexible technology that integrates three very common technologies: wireless sensors, the Internet and personal computers. Machine-to-machine communications appear to have a bright future in 2020, with the great development of better sensors, wireless networks and increased computing capability. Machine-to-machine communications will benefit both operators and users by means of large amounts of potential applications. For instance:

M2M communications can be used to more efficiently monitor the condition of critical public infrastructure, such as water treatment facilities or bridges, with less human intervention. Typically, M2M communications can
be used to monitor the traffic condition to give valuable guide information for drivers and alleviate the load of traffic in urban areas.

M2M communications are also envisaged to be widely applied in smart agriculture and healthy food. Real-time monitoring of plant's operational needs and the production capability will reach a finely control on the growth of vegetables and fruits, and move up the chain of command to forecasting purchasing and production capability chaining marketing strategy and ultimate sell-through.

M2M communications will also enable network operators to develop and bring to market innovative new services that leverage real-time intelligence from a wide range of devices in the connected world.

4.7 Virtualization of the Wireless Network

Today some network operators are turning to infrastructure sharing to reduce the cost of network deployment. The traditional shared deployments are mainly limited to concrete infrastructure sharing, such as sites, which have necessitated that participating operators agree upon the same technology, roadmap, and features. The result is significant loss of competitive differentiation among the operators, discouraging operators from embracing the technology and leading to fewer service offerings for customers.

A new solution to this challenge is virtualization of the wireless network, rather than traditional sharing. Operators who wish to share active infrastructure, particularly the base station subsystem (BSS), do so in order to reduce the cost of deploying and operating certain parts of the network. Besides the virtualization at the level of RAN, Core Network elements might also be run at the way of virtualization.

The challenge they are faced with is the ability to retain independent management and configuration control, and be able to apply software technology upgrades that differentiate them from their competitors.

4.8 Cloud Core Network

Incorporating Cloud technology into the wireless Radio Access Network has been widely studied to reduce networking costs these days. The cloud RAN is useful to separate the hardware and software for different wireless standards and various services and business models, as well as to meet the new system requirements for emerging wireless technologies, such as collaborative processing at different scales of network use.

The cloud technology will be also utilized in managing the wireless core network. In the wireless core network, some nodes, e.g., Home Agent, SIP Server, are always facing massive traffic/signal load, extending the cloud technology into the management of the telecom networks and wireless networks will make the network management much easier and smarter.

5. Environmental Constraints

5.1 Population Density in 2020

Population density varies in a wide range in different cities. Some examples taken between 1999 and 2004 are given in Table I [1].

<table>
<thead>
<tr>
<th>City</th>
<th>Population Density (person/km²)</th>
<th>City</th>
<th>Population Density (person/km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Huangpu District, Shanghai</td>
<td>126,542</td>
<td>19th arrondissement, Paris</td>
<td>25,454</td>
</tr>
<tr>
<td>St. Anthony Parish, Macao</td>
<td>98,776</td>
<td>Tokyo, Japan</td>
<td>13,333</td>
</tr>
<tr>
<td>Tondo District, Manila</td>
<td>64,796</td>
<td>Moscow, Russia</td>
<td>10,275</td>
</tr>
<tr>
<td>Kwan Tong District, Hong Kong</td>
<td>51,104</td>
<td>Madrid, Spain</td>
<td>5,198</td>
</tr>
<tr>
<td>Our Lady Fatima Parish, Macao</td>
<td>47,000</td>
<td>Berlin, Germany</td>
<td>3,809</td>
</tr>
<tr>
<td>Manhattan Community Board 8, New York</td>
<td>42,312</td>
<td>Atlanta, Georgia, US</td>
<td>1,221</td>
</tr>
<tr>
<td>11th arrondissement, Paris</td>
<td>40,672</td>
<td>Rosario, Argentina</td>
<td>630</td>
</tr>
<tr>
<td>Cairo, Egypt</td>
<td>36,618</td>
<td>Ottawa, Canada</td>
<td>279</td>
</tr>
</tbody>
</table>
For the highest population density, 130,000 person/km$^2$ in Mongkok, Hong Kong was reported in 2010 [2].

For highly dense areas, 40,000~50,000 person/km$^2$ seems to be a suitable range for many administrative units in Hong Kong, Macau, New York, Taipei, Shanghai, Paris, etc according to statistics taken from 1999 to 2004 [3].

The population growth rates in different countries typically ranges from 0% to 4% [2]. A full picture of the population growth rate in the world in 2011 is shown in Figure 5-1[5].

Figure 5-1: Population Growth Rate in the World

The population growth rate in Hong Kong, Macau, United States, Taiwan, Paris are 0.6%, 0.879%, 0.963%, 0.193%, 0.5% respectively [2][6]. For Shanghai, although the average growth rate is as high as 3.24%, the population densities in some highly dense administrative districts, such as Luwan District and Jin’an District, was reported to decrease from 2008 to 2009 [7][8][9].

Assuming a growth rate of 0.5% and leaving 10% margin to address uneven distribution of people in a city, the very high population density in 2020 can be predicted as around 55,000 person/km2, while the highest population density for NG-Wireless to consider may reach 150,000 person/km2.

5.1.1 Penetration Rate

The mobile Internet usage penetration rates in some countries are listed in Table II[10].

<table>
<thead>
<tr>
<th>County</th>
<th>Penetration</th>
<th>County</th>
<th>Penetration</th>
</tr>
</thead>
<tbody>
<tr>
<td>US</td>
<td>15.6%</td>
<td>Germany</td>
<td>7.4%</td>
</tr>
<tr>
<td>UK</td>
<td>12.9%</td>
<td>China</td>
<td>6.8%</td>
</tr>
<tr>
<td>Italy</td>
<td>11.9%</td>
<td>Singapore</td>
<td>3.0%</td>
</tr>
<tr>
<td>Russia</td>
<td>11.2%</td>
<td>Brazil</td>
<td>2.6%</td>
</tr>
<tr>
<td>Spain</td>
<td>10.8%</td>
<td>India</td>
<td>1.8%</td>
</tr>
<tr>
<td>France</td>
<td>9.6%</td>
<td>Indonesia</td>
<td>1.1%</td>
</tr>
</tbody>
</table>

The penetration rates will increase drastically from 2008 to 2020. In US, the number of active mobile Internet users increased 73% from May 2006 to May 2008, or 31.5% per year [11]. In China, the number of mobile Internet users increased 32.1% in the first half of 2009, or 74.5% a year. If such a trend continues, then mobile Internet usage penetration in both US and China would saturate before 2020 [12].
The saturation level of the penetration rate of actual mobile communication users (not simply recorded subscribers) may vary in different countries, mainly depending on the age structure of the population [13]. Assuming the penetration rate would saturate at a level close to the percentage of population ages over 15, the saturation level in Hong Kong, Macau, New York, Taipei, Shanghai, Paris can be estimated as 86%, 84%, 79%, 83%, 91% and 82% respectively [7][14][15]. Higher penetration level may be expected due to better education in 2020.

5.1.2 User Density

User density in 2020 $D_{\text{user,2020}}$ may be calculated as population density $D_{\text{popu,2020}}$ multiplied by the penetration rate $\lambda_{2020}$.

As afore mentioned, it may be estimated from the population density $D_{\text{popu,y0}}$ in year y0, the annual population growth rate $r_{\text{popu}}$, the penetration rate $\lambda_{y0}$ in year y0, the annual growth rate of the penetration rate $r_{\lambda}$, and the saturation point of the penetration rate $\lambda_{\text{sat}}$ with a margin $\beta$ by the following equation:

$$D_{\text{user,2020}} = D_{\text{popu,2020}} \cdot \lambda_{2020} = (1 + \beta)D_{\text{popu,y0}}(1 + r_{\text{popu}})^{2020-y0} \cdot \min\{\lambda_{y0}(1 + r_{\lambda})^{2020-y0}, \lambda_{\text{sat}}\}.$$  \hspace{1cm} (1)

Table III – User Density for Typical Regions in 2020

<table>
<thead>
<tr>
<th>Scenario</th>
<th>User Density (user / km$^2$)</th>
<th>Memo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most Dense Region (MDR)</td>
<td>130,000</td>
<td>Mong Kok, Hong Kong or central Huangpu District, Shanghai</td>
</tr>
<tr>
<td>Higher Dense Region (HDR)</td>
<td>50,000</td>
<td>Some commercial centers and residential centers in Hong Kong, Macau, New York, Taipei, Shanghai, Paris, etc.</td>
</tr>
<tr>
<td>Dense Region (DR)</td>
<td>25,000</td>
<td>Dense cities</td>
</tr>
<tr>
<td>Urban Region (UR)</td>
<td>5,000</td>
<td>Normal cities</td>
</tr>
<tr>
<td>Suburban Region (SR)</td>
<td>1,000</td>
<td></td>
</tr>
<tr>
<td>Rural Region (RR)</td>
<td>200</td>
<td></td>
</tr>
</tbody>
</table>

Another special region with high mobility requirement not listed in the table is highway. Typically, the car density in highway region is a function of the number of lanes, lane width and required minimum car distance. The highest speed allowed in highway is about 120km/h. In comparison to the above five regions defined by user densities, this special region can be described by car density instead of user density.

5.2 Regulatory Aspects

Scarce availability of wideband spectrum is driving changes in the regulatory environment. The elimination of broadcast TV has opened up new spectrum, however, there is not much else that is available at this time that is suitable for mobile communications. FCC is leading the new era of spectrum management in North America with a variety of approaches to addressing spectrum scarcity. Fragmented spectrum blocks and allowing sharing or leasing of licensed spectrum are some of the recent regulatory trends. These trends are motivating innovation in the approach to radio system design for efficient spectrum usage, possibly driving the emergence of cognitive systems into the mainstream. There is also a significant and increasing stress on unlicensed spectrum with the popularity of WiFi and other technologies in the unlicensed space. These approaches may provide new technology opportunities either to help extend the incumbent operator’s reach or to service new operators.

There is always the tradeoff to consider between investing in new spectrum or growing the infrastructure with smaller cells to support higher capacity. The thirst for new spectrum will likely prevail since spectrum has an appreciating value while infrastructure is always depreciating. A combination of these strategies is the most likely scenario.
5.3 Energy Constraints

The operation of multiple Radio Access Technologies (RATs) both in the network and in the devices will increase the energy demands in the wireless ecosystem. There will be a need to address ways in which the multiple radios can be employed efficiently to ensure that multiple idle radios are not consuming unnecessary power. However, the radio by itself, be it in the access point or in the device, only consumes a small fraction of the total energy required to operate the wireless network. Therefore, the design of the radio interface does not really need to be constrained by placing energy limitations at the cost of efficient use of spectrum or efficient operation.

6. Business Model

The vision of NG-Wireless developed taking into consideration the current and emerging business trends around the world. Of course, a major key player in the future will continue to be the “classic” operator which owns the entire infrastructure of its network, operates and manages all user services, and takes care of all user experience. However, in addition to “classic” operators, we expect that several new types of operators will emerge.

In particular, a trend that cannot be overseen and is expected to play out in the short- to mid-term is operator consolidation. Operators are likely to enter into cooperation agreements, joint ventures, or mergers to save on costs. Operators, such as O2 and Vodafone for example already share cells in certain EU countries and we expect that others will follow this trend. The high costs for rolling out LTE may accelerate this trend. In the process operators are likely to increase infrastructure sharing, including cases where different operators use the same network elements. Virtualization will be a key technology in achieving this and already the foundation concepts and basic building blocks are tested. By the end of the decade, new business relationships which will be enabled through resource virtualization and sharing will introduce new opportunities and new players in the value chain.

On the network operation and management area, new business opportunities for both operators and vendors arise as third parties (including vendors’ professional services arms) will operate some of the networks following a form of outsourcing. This trend, which has recently drawn our attention in the North American market, is also to be strengthened through advances in virtualization. For example, a Business Actor X could operate and manage physical resources originally owned by Operators A and B, to provide services to subscribers of both operators as well as Operator C which has customers in the area but has not invested in infrastructure rollout. Instead, Operator C will contract Business Actor X, which may be the professional services arm of a well-established vendor, a joint venture between Operators A and B, or either of the operators under a subsidiary. Business Actor X, then, will employ the virtualized resources of the joint A-plus-B existing infrastructure to deliver the services on behalf of Operator C. For subscribers of Operators A, B, and C, none of these business interactions is visible. Instead all subscribers think they use separate physical infrastructures.

Another trend emerging in recent years and which we expect will become even more prominent in the coming years is that different business players will own different parts of the network. For example, each of the transport, access, services and subscription components could be managed and owned by different entities. Cloud computing and storage will also play a key role in this development. Personalized contents and service delivery as well as new applications areas such as application mobility, augmented Internet, 3D media, and so on, will further foster this trend as novel technologies are to be developed and marketed by different players. Operators, however, need to be able to participate in this emerging value chain and thus their core network infrastructure has to move towards a cognitive, energy- and cost-efficient core, which takes advantage of novel virtualization techniques, adopts next-generation name resolution and contents delivery mechanisms, and enables contents delivery over the best path given the current network context.

It is important to highlight that this list is, of course, not exhaustive. However, we do list the possibilities that NG-Wireless technologies can support in addition to the classic operator case. In addition, we also foresee changes in Operation and Management. For example, the issue of managed vs. unmanaged networks as well as the use of combinations of the two to extend coverage, increase end-user performance and cut costs will become more pertinent.

So far we discussed the possibilities which are likely to occur in developed markets and are so likely to influence developments in the majority of developing markets and regions. In addition, however, NG-Wireless Architecture will need to specially cater for operators that require customization and partial deployment aiming to address the needs of developed and developing markets. With respect to the latter, NG-Wireless will strive to
develop an architecture that is able to provide down-stripped offerings which provide reduced services for low-cost system deployments.

In short, NG-Wireless aims at addressing the needs of a significantly more diversified telecommunication market.

7. Traffic Model until 2020

7.1 Traffic Model and Throughput Requirements - Common

The traffic expectations of Ericsson (see [45]) and Cisco (see [46]) till 2015 are roughly in line with each other and with the expectations of Huawei. Huawei has been cited during Mobile World Congress 2010 (see [49]) with the statement of 1000 times traffic increase until 2020 corresponding to 85GB transferred data per subscriber per month. A similar but slightly slower growth (see Figure 7-1), i.e. 500 times corresponding to about 57GB per month per average subscriber, is expected in this paper for Western Europe (WE).

Note: 60GB per month is generated by a DSL internet subscriber at a constant bit rate of 2Mbit/s based on the average online time of 136min in 2009 (see also Figure 7-5). It cannot be expected that all DSL data traffics become mobile traffic (complementary use) so that there is still margin left for increase in online time and service needs (see also below).

The proportion between handset traffic and cellular modem traffic is changing in favor of the handset traffic, which is going to have a share of 30% in 2020 (this is different to Ericsson forecast). This expectation is based on rapidly improving capabilities of handsets and availability of applications.

Additionally, cellular modem traffic is to a large extent nomadic (about 80%) and dramatic increases of cellular traffic will very likely cause counter measures, i.e. traffic offloading.

Figure 7-1: Growth of transferred data in Western Europe (based on [27] and partial on [46])

Note: The basis “all subscribers” refers to the population aged above 14 since mobile (voice) penetration is developed countries is already above 100% and does not reflect the active users. This is due to the effect that lots of subscriptions are still reported but due to provider change etc. are no longer in use.

However, such overall traffic figures are not sufficient to determine network requirements based on it. Needed are figures for network dimensioning are:

- throughput (bit rate, i.e. R) per user during busy hour and
- QoS of used services
There is the tendency that all internet applications, which are used via fixed internet access (see Figure 7-2), are also used via mobile access (see [39], [47]). Some applications may even be accessed more frequently via mobile access that via fixed access, e.g. as already happening for social networks in Japan (see [48]).

![Figure 7-2: Relative usage frequency of internet applications via fixed line access (see [47])](image1)

**Note:** Web-traffic refers to the following: search engine usage, online news (incl. RSS feeds) and online banking. Video is a separate category even though that online news contain more and more video clips.

The frequency of usage does not reflect the transferred data related to it. The best example is video, which is estimated to have the biggest growth in traffic but accounts for a much smaller portion in usage frequency.

![Figure 7-3: Relative portion of internet applications on transferred data (see [46])](image2)

However, the used device, i.e. handset or laptop or equivalent device with cellular modem (thus term cellular modem is used to refer to such devices) has also significant impact on the generated traffic (see [28]). The fixed access internet user visited in US in 2008 14 times more web sites than the mobile user. Some similar result can be assumed for laptop (cellular modem) users compared to handset users. Additionally are data rates adapted to the characteristic of the device, e.g. live video with H.264 AVC is provided at 1Mbit/s for handsets but is at 2 to 4M bit/s for laptops.

The voice service comes on top of the services stated above. There are quite efficient codec available (iLBC or AMR), which provide fair voice quality at low bit rate (AMR via IPv6 needs 36.8kbit/s, iLBC needs 29.3kbit/s). Packet oriented mobile networks will carry also voice traffic, while CS-oriented are considered to

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exist only during a migration phase. The special requirement of voice (and also of video conferencing via e.g. H.264 AVC) is the low required latency and quite high packet rate (sample rate is 20ms, which causes 50 packets/s). Stored video, e.g. YouTube, have a high throughput demand but latency is less of an issue here due to large packet size and buffering.

There is no big impact on transferred data if voice is completely carried by packet oriented domain (see Figure 7-4). However, it is necessary to be prepared to support latency and packet rate requirements.

The growth in throughput for handset data and cellular modem data is illustrated in Figure 7-5. The VoIP traffic is also shown but this is considered to remain stable since liberalisation of Western Europe (WE) telecom market led already to a stable situation. The data rate in handsets is in the beginning reasonably low but increase faster than the cellular modem throughput. The average mobile time is estimated to about 40min (handset and cellular modem together), which represents 30% of the average internet online time of 136 min in 2009 (see [47]).
The most interesting issue for network dimensioning is the throughput in the busy hour (BH). This figure was in past not published but despite the transferred data during month or year has been given. The reason could be that the BH bit rates were quite slow due to long data session and low amount of transferred data. Since mobile data subscription penetration (Figure 7-6) as well as transferred data per subscriber (see Figure 7-4) increases dramatically this busy hour (BH) considerations needs to be done.

Note: Mobile data subscription and mobile internet is used synonymously in this document since it is assumed that most data access goes to internet even though that also provider applications or corporate networks are targets for mobile data traffic.
traffic. This is covered by assuming 25% of data traffic in BH and 20% of voice traffic during BH.

![Figure 7-7: Internet usage distribution during 24h (Germany, [47])](image)

The overall forecast up to 2020 of throughput during busy hour is shown in the chart below. The throughput is provided on the base of all subscribers (thus having an average across all subscribers) and on the base of only such subscribers with mobile internet subscription. The later cause majority of the throughput since VoIP portion decreases from 23% in 2009 (if all voice traffic would be carried by PS-domain) to less than 1% in 2015.

Due to increasing penetration of mobile data subscriptions is the gap between throughput based on all subscribers and throughput based on subscribers with mobile data subscriptions closing.

Relevant for network dimensioning is the throughput per subscriber on the basis on all subscribers, which is 1053kbit/s in BH. The increase of mobile internet subscriptions to values above 72% (see Figure 7-6) would increase the expected throughput (see Figure 7-9).
The expected dramatic increase in traffic as illustrated in section 7.1 has to be evaluated from the vendor as well as from the customer (operator) point of view. The usual way to increase network capacities is the extension of the existing network unless there is a technology change or a swap of the equipment of a vendor if the customer is un-satisfied.

An annual increase of the (core) network capacity by 76%, which is assumed if 500 times more traffic is handled in 2020 can be discussed in light of two illustrative scenarios.

Scenario 1 assumes the extension of the capacity by simply adding new equipment. This scenario results in excessive increase in OPEX in long term even thought 90% of the original OPEX is fixed (base effort) and only 10% is variable, depending on the number of nodes (maintenance of addressing, routing, ...). However, the initial effort is comparably low, which is an advantage compared to scenario 2, discussed below.

Values above 1 of the profit margin in Figure 7-10 indicate an increase in profit margin, while values below indicated a decrease in profit margin. Here, profit margin is a relative value and indicates the direction of development. Nevertheless values below 1 can still come along with an increase of profit in absolute numbers but the relative profit (cost versus return/revenue) is decreasing.

Figure 7-9: Throughput per subscriber during BH
The more likely scenario is scenario 2 (see Figure 7-10), where existing nodes are replaced but it is assume that the performance of that (new) nodes grow according to Moore’s law, which states performance increase of 100% within 18 months. This gives a sustained annual increase of about 67% in node performance and requires some effort from the equipment vendor.

The OPEX for replacement is high against the incremental capacity extension but this drawback exists only in the beginning. Long term, the replacement scenario is by far a better solution. The replacement is basically the exchange of existing nodes with new nodes with increased performance. Additional equipment is only needed to close the gap between 76% increase in demand and 67% increase in performance.

The advantages of the replacement scenario are:

- OPEX for network extension (addressing, routing, …) is low since nodes are primarily replaced
- Increase in power consumption and foot print is reasonable low
- Gaining new customers is more likely since replacing paves the way for a vendor swap
However, there are also some risks. Own installed equipment is swapped out but primarily there is the risk that the customer requests to have the installation OPEX as part of the equipment sold. This shifts the risk of OPEX increase due to sub-optimal equipment configuration approach to the vendor. Working autonomous configuration approaches would then immediately decrease vendor costs and the issues should thus be addressed.

![Graph showing OPEX vs Revenue, Weighted OPEX/CAPEX vs Revenue; 4:1]

Figure 7-11: Profit margin for NW capacity increase scenario 2 (replacement)

7.3 RAN related Conclusions concerning Throughput Requirements

7.3.1 Throughput Requirement in 2020

1) Throughput Requirements of Services

Throughput requirement per user \( T(s) \) introduced by service \( s \) may be estimated according to the bit rate requirement of each service, service usage and user behavior, etc.

\[
T(s) = P_u(s)P_t(s)R(s)
\]  

(2)

Where \( P_u(s) \) is the percentage of users using service \( s \), \( P_t(s) \) is the probability that service \( s \) is used by wireless devices of a user at a given time, \( R(s) \) is the bit rate required to deliver service \( s \).

For \( P_u(s) \), the typical percentage of mobile users using various data services in 2008 is shown by the green curve in Figure 7-12. The services considered include video/TV, music, position/GPS, software/application download, mobile web browsing, text/short message, etc. For example, \( P_u(s) \) for mobile video service is 5%.

Please notice that the number of persons watching video on their way may be much more than the number of mobile video users. This is because people can download video programs at home using wired networks and then transfer the files to their mobile devices to watch outside. (Notes: Indeed and this can lead to tremendous savings in bandwidth and energy consumption at once. But it requires intelligent application, network, subscriber management, particular business models and DRM conditions.)
For Pt(s), user behavior statistics are needed. For example, the average time a user watches mobile video in US is 3 hours and 15 minutes per month [11]. Assuming typical mobile video service is evenly distributed in 2 hours a day and 30 days a month, Pt(s) for mobile video service is around 5%.

For R(s), different video formats need to be considered. For example, the required bit rate is 1~2 Mbps for WVGA on mobile phone or netbook and 6~8 Mbps for HD1080i on devices embedded in car using MPEG-4 [13]. Latest development in H.265 has reported 20% average bit reduction [17]. Assuming 30% further bit reduction will be achieved in the coming 10 years, WVGA and HD1080i would require 0.5~1 Mbps and 3~4Mbps respectively in 2020. Assuming 80% users would watch WVGA at 0.75 Mbps and 20% users would watch HD1080i at 3.5 Mbps, the average bit rate of video service R(s) may be assumed to be about 1.3 Mbps.

Using the above parameters, the throughput requirement per user introduced by video service in busy hour, averaged over all users including active and inactive, can be calculated as:

\[ T(\text{video}) = P_u(\text{video})P_t(\text{video})R(\text{video}) = 0.05 \times 0.05 \times 1.3 \text{Mbps/user} = 3 \text{Kbps/user} \]

(3)

However, it is very difficult to estimate the parameters of Pu(s), Pt(s) and R(s) for all the services in 2020. First, we do not have the statistics of all the current services in use. Second, such statistics, esp. Pt(s) depending on user behaviors, may change a lot in the coming 10 years. Last, the bit rate requirements of some new services such as 3D video are still not clear.

2) Throughput Requirement per User

Theoretically, the throughput requirement per user \( T_{user} \) can be calculated as the sum of the throughput requirement introduced by each service:

\[ T_{user} = \sum_{s=1}^{S} T(s) \]

(4)

Where S is the number of services provided by wireless access.

However, as mentioned above, it is difficult to predict T(s) for all the services in 2020. To overcome this difficulty, we directly use the prediction made by UMTS Forum for the total mobile traffic amount in 2020 [18].
According to the prediction in [18], the total mobile traffic for all service categories in 2020 would be 36.39 Mbytes in a busy hour per subscriber. This means the required mobile data rate averaged over a busy hour would be $T_{user} = 80$ Kbps per subscriber.

This prediction was made in 2005 mainly for European countries which is already some years old. It may underestimate the fast growth of new killer services and M2M applications. Also this would not be very ambitious as a target. Cisco estimates that with current technologies, the average European mobile broadband (MBB) subscriber will record monthly traffic of 4 GB in 2012 (this is HSPA, not LTE or anything exotic). Finland has already regulated 1 Mb/s broadband as a legal right for all citizens to foster broadband deployment across the country. Other countries will follow in the coming years.

According to the prediction in Figure 7-13, the average throughput per cellular subscriber on the basis of subscribers in use may be 1.46 Mbps in BH. Considering higher peak data rate and the possibility of higher throughput requirement from new (e.g. M2M) applications in the future, we should leave a throughput margin in system design. Assuming 100% throughput margin, the peak data rate, averaged over all users including both active and inactive, would be $T_{user} = 3$Mbps per user.

Such a high average data rate may seem doubtful to some of our Chinese colleagues. However, it may be justified by experience of our colleagues in western countries – they saw most of the people watching e-books or videos on their way home after working hours. In order to avoid interfering with others, people use earphones when they watch video or listen to music in bus or metro train. Such user behaviors should be common in developed countries such as US, Canada, Korea, Japan and European countries in 2020.

But such user behaviors may not be applicable to developing countries, such as China and India. Although much denser population in these countries may eventually lead to much heavier throughput requirement when they become developed countries in this century (perhaps around 2050), it does not need to be considered in this document on vision in 2020.

Unfortunately, we do not have any source for prediction of service statistics and user behavior in China or India in 2020. So currently we have to make our vision according to requirements in developed countries.

However, we think this forecast for the cellular traffic is somehow optimistic. There will be anyway a counter-reaction and search for alternative to offload the traffic from air when it gets into this region of throughput.

In the following, we will assume that 1Mbps cellular traffic per user should be provided by telecom operators in 2020. This should be an averaged throughput for all users including both active and inactive, i.e., the active users can reach 10 Mbps when the convergence ratio is 10.

3) Throughput Requirement per Area

Throughput requirement per area $T_{area}$ may be estimated as the product of user density $D_{user}$ and throughput requirement per user $T_{user}$. 

![Business Busy Hour Traffic by Activity - 2020](image)
\[ T_{\text{area}} = D_{\text{user}} T_{\text{user}} \] (5)

So the peak throughput requirements in some typical regions in 2020 may be estimated as:

- Higher Dense Region: 50 Gbps / km²
- Dense Region: 25 Gbps / km²
- Urban Region: 5 Gbps / km²

7.3.2 Radiation & BS Power Requirement

High throughput requirement in NG-Wireless may lead to high BS Tx power. However, BS Tx power should be limited according to regulations on electromagnetic radiation and requirements of maximum total BS Tx power. This section investigates these two constraints in NG-Wireless system design.

1) Requirement of Electromagnetic Radiation

The power density limit specified by ICNIRP is \( f/200 \) W/m² for 400~2000 MHz and 10 W/m² for 2~300 GHz [19]. This standard is widely used in European countries and Australia, Singapore, Brazil, Israel, Hong Kong, etc.

The power density limit specified by IEEE is \( f/1500 \) mW/cm² for 300~1500 MHz and 1 mW/cm² for 1.5~100 GHz [20]. This standard is used US, Canada, Japan, Korea, Taiwan, etc.

The power density limit adopted by Ministry of Environmental Protection of China in 1988 was 0.4 W/m² for 30~3000 MHz, much stricter than the international standards [21].

It should be noted that the power density limit is set for the radiation from all the wireless systems. For a single wireless communication system among them, the power density constraint is much stricter.

2) Requirement of BS Tx Power for Radiation

We assume the fixed antenna patterns for 3-sector cell sites in LTE as the typical antenna pattern. According to [22], the horizontal antenna gain \( A_h(\phi) \) and vertical antenna gain \( A_v(\theta) \) can be modeled by Eq.(5) and Eq.(6), respectively:

\[
A_h(\phi) = -\min \left[ 12 \left( \frac{\phi}{\phi_{3\text{dB}}} \right)^2, A_m \right] \tag{6}
\]

Where \( \phi_{3\text{dB}}=70 \) is the horizontal 3dB beam width and \( A_m=25 \text{dB} \).

\[
A_v(\theta) = -\min \left[ 12 \left( \frac{\theta-\theta_{\text{tilt}}}{\theta_{3\text{dB}}} \right)^2, SLA_v \right] \tag{7}
\]

Where \( \theta_{\text{tilt}} \) is the electrical antenna downtilt, \( 3\text{dB}=10 \) is the 3dB beam-width and \( SLA_v=20 \text{dB} \).

Figure 7-14 shows the antenna radiation gain in horizontal and vertical planes of a 3-sector cell site normalized in comparison to omni-directional antennas.
The total power density gain can be estimated as:
\[
\max \{ G(\phi, \theta) \} = \max \left\{ A_h(\phi) \right\} + \max \left\{ 10 \log_{10} \left( \frac{\pi \cdot h^2}{\sin^2(\theta)} \right) + A_v(\theta) \right\}
\] (8)

For horizontal antenna radiation, the maximum normalized antenna radiation gain is about 2dB. For vertical antenna radiation, both the normalized antenna gain and the geometry have to be considered jointly in calculating the power density gain.

Our simulation results of the total power density gain are shown in Figure 7-15:

According to the simulation results, the maximum power density gain is about -32dB/m², -26dB/m² and -20dB/m² for the antenna height of 32m, 16m and 8m, respectively. It is interesting to find out a conclusion that the position with richest radiation is not right below the BS antenna. It is near the place facing the center of the main beam of the BS antenna.

Using the power density limit of 10 W/m², we can derive that for a 3-sector cell site, the maximum BS Tx power allowed is about 15KW, 3.5KW and 900W for the antenna height of 32m, 16m and 8m, respectively. For the power density limit of 0.4W/m² in China, this means a BS Tx power limit of about 600W, 140W and 36W.

Figure 7-16 shows the maximum power density gain \( G_{\text{radiation}} \) as a function of the antenna height.
The maximum public radiation power density radiation introduced by a microcell may be estimate as:

\[ D_{\text{radiation}} = G_{\text{radiation}} \cdot P_{\text{BS}} \] (9)

Where PBS is the actual Tx power at the BS.

The simulations results of the radiation power density with some system configurations are listed in Table IV and Table V in section 7.3.4.

Other wireless systems may also contribute to the radiation. For example, the power density limit of 10 W/m² may apply to the radiation from not only LTE systems at 2GHz, but also WiFi at 2.4 GHz and other wireless systems working in 2~300 GHz. This situation of radiation from other wireless systems may vary in different countries.

### 3) Requirement of BS Tx Power

In LTE-A, the current maximum total BS power is 49 dBm or about 80 W [22]. A special additional regional BS output power requirement is also identified for Band 34 operation in Japan. This regional requirement specifies 20W, 40W, 60W maximum output power for 5MHz, 10MHz and 15MHz bandwidth, respectively [23]. So LTE-A should have plenty of room to meet radiation requirements.

It should be noted that the required BS power is dependent on antenna height and antenna configuration for cell coverage. Smaller cell or lower antenna height would lead to smaller required BS power. However, the radiation density is somehow independent to the antenna height if cell coverage is kept the same by using different antenna configurations. Therefore the only way to reduce radiation density is to reduce the cell size. From this point of view, the total BS power constraint is “softer” than the radiation protection constraint.

Apart from the regulations for electromagnetic radiation protection, BS Tx power is also limited by other considerations, e.g. requirements on spurious emissions and interference for system coexistence.

It is also preferred to keep BS power reasonably low from the viewpoint of equipment realization, operational cost and green radio. In the following, we will assume a maximum total BS power limit of 49 dBm.

### 7.3.3 Basic Features of NG-Wireless RAN Side

#### 4) ISD Requirement for Capacity

According to IMT-A requirements, the peak data rates would reach 1Gbps for low mobility and 100 Mbps for high mobility. However, peak data rates are not very meaningful in practice.

According to LTE-A requirements, the average spectrum efficiency would reach 3.7 bps/Hz/cell in DL and 2.0 bps/Hz/cell in UL. Although higher spectrum efficiency of up to 5.5 bps/Hz/cell has been reported in LTE-A self-evaluation, we cannot use it as our assumptions because it is only for indoor scenario. For other scenarios, the highest spectrum efficiency reported is 3.68 bps/Hz/cell for LTE-A FDD using JP-CoMP 4tx. Therefore we just assume the average spectrum efficiency of $\eta=3.7$ bps/Hz/cell in microcell scenario.

The maximum bandwidths proposed for carrier aggregation in LTE-A is currently 100 MHz[23]. Because
wireless access through WLAN pipes is much cheaper than LTE-A cellular pipes, low-mobility users may prefer not to use LTE-A cellular pipes for wireless access whenever WLAN is available. Assuming 60% of the total traffic would be supported by other wireless access such as WLAN in 2020, the maximum inter-site distance (ISD) required with 3 cell/sectors per site can be estimated by:

\[
\text{ISD} = \left( \frac{\eta \cdot BW}{\sqrt{3/2 \cdot T_{\text{area}}}} \right)^{1/2}
\]

(10)

The calculation results are listed in Table V and Table VI in the next section.

5) BS Power Estimation

Because the BS power constraint is “softer” than the radiation protection constraint, we consider the radiation protection constraint first.

Here we assume the antenna radiation pattern is fixed and hence the antenna height is proportional to the cell radius. Users are assumed to be evenly distributed within the cell coverage according to the user density of typical regions. Urban microcell outdoor channel model with outdoor to in-car penetration is used.

To estimate the BS Tx power needed for each user, assumptions on link budget parameter for downlink is summarized in Table IV.

Table IV – Link Budget for Downlink

<table>
<thead>
<tr>
<th>UE Receiver</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Receiver Noise Density</td>
<td>-174 dBm/Hz</td>
</tr>
<tr>
<td>Receiver Noise Figure</td>
<td>7 dB</td>
</tr>
<tr>
<td>Receiver Interference Density</td>
<td>-165 dBm/Hz</td>
</tr>
<tr>
<td>Rx Total noise plus interference density</td>
<td>-163 dBm/Hz</td>
</tr>
<tr>
<td>Average Bit Rate per User (R_{user})</td>
<td>1 Mbps</td>
</tr>
<tr>
<td>Average Spectrum Efficiency (\eta)</td>
<td>3.7 bps/Hz</td>
</tr>
<tr>
<td>Occupied Bandwidth (B=R_{user}/\eta)</td>
<td>540 KHz</td>
</tr>
<tr>
<td>Effective noise power</td>
<td>-105.5 dBm</td>
</tr>
<tr>
<td>Required Eb/N0</td>
<td>2 dB</td>
</tr>
<tr>
<td>Scheduling / HARQ gain</td>
<td>3 dB</td>
</tr>
<tr>
<td>Cable, connector, combiner, body losses, etc.</td>
<td>1 dB</td>
</tr>
<tr>
<td>Receiver Implementation Margin</td>
<td>2 dB</td>
</tr>
<tr>
<td>Receiver Sensitivity (S)</td>
<td>-103.5 dBm</td>
</tr>
</tbody>
</table>

Channel Propagation

<table>
<thead>
<tr>
<th>Lost scale fading (F)</th>
<th>LOS : 22.0 log_{10}(d) + 28.0 + 20 log_{10}(f_c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Penetration Loss</td>
<td>10 dB</td>
</tr>
<tr>
<td>Average Shadow Fading Loss (std 4dB)</td>
<td>1 dB</td>
</tr>
<tr>
<td>Fast fading loss margin</td>
<td>4 dB</td>
</tr>
<tr>
<td>Channel loss (L)</td>
<td>F + 15 dB</td>
</tr>
</tbody>
</table>

BS Transmitter

<table>
<thead>
<tr>
<th>BS antenna height (h)</th>
<th>h = 32 * ISD/500 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS antenna vertical angle (\theta)</td>
<td>\theta = \tan^{-1}(h/r) degree</td>
</tr>
<tr>
<td>BS antenna horizontal gain</td>
<td>A_{h}(\phi) dB</td>
</tr>
<tr>
<td>BS antenna vertical gain</td>
<td>A_{v}(\theta) dB</td>
</tr>
<tr>
<td>Cable, connector and combiner losses</td>
<td>3 dB</td>
</tr>
<tr>
<td>Required Tx Power at BS</td>
<td>S + L + A_{v} - A_{h} + 3 dB</td>
</tr>
</tbody>
</table>

The required Eb/N0 is dependent on the channel coding performance. According to [24], we assume it to be about 2 dB using LDPC in LTE-A. The high bit rate of 1 Mbps would lead to long code length, which helps ensure good coding performance.

The simulations results are listed in Table V and Table VI in the section 7.3.4.
### 7.3.4 System Requirements of RAN Side

In order to help identify the potential challenges, some typical simulation results assuming traditional cellular network architecture are summarized in Table V and Table VI. Throughput requirement per user, averaged over all users including both active and inactive, is assumed to be 1Mbps.

#### Table V – Dense Region (25000 wireless access users per km²)

<table>
<thead>
<tr>
<th>BW (MHz)</th>
<th>Cell Radius (m)</th>
<th>ISD (m)</th>
<th>BS Tx Power (dBm)</th>
<th>Radiation Density (W/m²)</th>
<th>BS Density (site/km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fc=2.3GHz</td>
<td>20</td>
<td>58</td>
<td>101</td>
<td>12</td>
<td>8.1E-05</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>83</td>
<td>143</td>
<td>21</td>
<td>3.8E-04</td>
</tr>
<tr>
<td></td>
<td>60</td>
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<td>130</td>
<td>226</td>
<td>38</td>
<td>7.8E-03</td>
</tr>
</tbody>
</table>

#### Table VI – Rural Region (200 wireless access users per km²)

<table>
<thead>
<tr>
<th>BW (MHz)</th>
<th>Cell Radius (m)</th>
<th>ISD (m)</th>
<th>BS Tx Power (dBm)</th>
<th>Radiation Density (W/m²)</th>
<th>BS Density (site/km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fc=2.3GHz</td>
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<td>1132</td>
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<td>924</td>
<td>1601</td>
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<td>3.5E-02</td>
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<td>2532</td>
<td>78</td>
<td>5.6E-01</td>
</tr>
</tbody>
</table>

According to the results shown above, the traditional cellular networks would face great challenges in 2020:

- Extremely high cost for BS sites 100 times denser than current 2G/3G networks in dense regions, together with the backhaul needed to support these high-throughput dense sites.
- Great amount of cost for BS power consumption 100 times higher than current BS equipments in rural regions, together with the electromagnetic radiation problem.

In order to overcome these great challenges and help operators make better profit from the future market, we have to introduce a new RAN architecture and an enhanced air interface.

- The new RAN architecture should wisely combine the capabilities of different wireless systems, such as macro cells, micro cells, femto cells, WiFi, DAS, etc., to provide low-cost economic...
services with different values and requirements to the users in various scenarios.

- The enhanced air interface should be able to fully exploit the advantages of advanced technologies, such as intelligent interference avoidance, cooperative data transmission, etc., to break through the wireless bottleneck.

To further improve system capacity (Average Area Throughput), there is no way other than using dense small cells. Considering cost, the strategy for dense small cells deployment may consider two architectures, i.e. "Centralized" and "Distributed".

- Centralized: when fiber resources are rich (RRU can be distributed by fiber/WDM), centralizing all RAN computing/processing (Baseband, RRM, etc) is preferred. By this means, two benefits can be achieved: system capacity gain due to nearly ideal network MIMO, and cost reduction/load sharing due to centralized processing. At the same time, cloud computing technology can be used to further reduce the deployment cost of dense small cells through flexible and efficient load balancing.

- Distributed: when fiber resources is not enough, distributing RAN computing/processing (Baseband, RRM, etc) is preferred, i.e. dense Pico-BTS deployment is used. In order to reduce the backhaul cost, we try to avoid a mesh interconnection, and thus like that each Pico is as "independent" as possible. Also, this architecture should overcome many difficulties as shown in our charter.

To meet such system requirements for RAN in 2020, a lot of technical research works need to be carried out. Some identified key research topics are listed in section 8.1.
7.4 Core related Conclusions concerning the Requirements

The concise conclusions are given in section 7.4.1, while some details to back the conclusions are provided in section 7.4.2

7.4.1 Summary

Conclusions

- An optimization of the network architecture, especially the reduction of the number of nodes in the traffic path is important to reduce the high network load.
- The dynamic resource management is vital to avoid the need for over-provisioning to ensure QoE. Its assumed that resource self-optimisation is required
  - to handle the local fluctuation in traffic demand,
  - changing demand of service (with different QoS requirements),
  - make effective use of external resources
  - support/inter-work with optimized user traffic handling
- The need for (at least partial) introduction of self-configuration and self-optimisation is triggered by the
  - large number of nodes
  - use of pooling for network redundancy and scaling
  - need to avoid over-provisioning and thus dynamic network re-configuration
  - increase of inter-connects and
  - use of PDN-GW functionality adjacent to radio nodes for local inter-connect (and thus increase that number significantly)
  - use of (numerous small) external resources
- Different types of virtualisation (resource abstraction, function virtualisation and cloud computing) are technologies that enable scaling and support self-optimisation.

The work on the issues listed above is seen as vital to keep core networks scalable, manageable with reasonable effort and avoid over provisioning since these increase energy consumption significantly.

7.4.2 Rational

The forecasted throughput, which has been determined in section 7.1, is relevant for the radio interface as well as for the core network. The consequences shall be investigated based on the example network illustrated in Figure 7-17. The highest ISD determined in 7.3 is used to calculate the number radio elements for a specific area.

However, using smaller ISD would decrease the throughput per backhaul connection; increase the number of backhaul connections as well as increasing the proportion of radio nodes to core nodes. The conclusions would in principle not change but get more stringent, e.g. increase of number of node increase the effort to set up the network configuration even more.

The example network serves an area of 125,000km$^2$ and 93Mio subscribers. This results in a subscriber density of 744 #/km$^2$, that is much higher than in Europe (e.g. Germany has 231 #/ km$^2$) and is equivalent with the density of districts Shandong and Jiangsu, which have a quite high population density. The following parameters are assumed:

- 50 core sites
- each core site serves (different distribution even with areas of highest density would not change the principles):
  - 200 km$^2$ of UR (5000 #/km$^2$) = 540 RAN nodes
  - 500 km$^2$ of SUR (1000 #/km$^2$) = 270 RAN nodes
  - 1800 km$^2$ of RR (200 #/km$^2$) = 194 RAN nodes
- 6 inter-connects to internet /application domain

The number and location of inter-connects is done as it is currently in networks usually done. The
discussion to increase the number is still ongoing and there are several issues to consider, including regulation, pricing and technical feasibility concerning network wide available services in internet (on application server).

![Diagram](Figure 7-17: Example network to illustrate the core requirements)

The throughput considerations need to include the protocol stack of the user data path. It can be assumed that even in an optimized architecture there is a need to have (at least a short) tunnel (see Figure 7-18).

![Diagram](Figure 7-18: Example stack of network to illustrate the core requirements)

The additionally required throughput capacity depends on the packet size, which in turn depends on the service. Voice for example requires nearly twice the throughput of the application layer (0.6kbit/s per subscriber during busy hour, see Figure 7-19) in core network (1.17kbit/s) due to the small packet size and thus high packet rate.
The backhaul of each RAN node (there are 1004 connected to each core site) in 2020 is challenged as following:

- 2.08G bit/s throughput
- 170k packets/s

This puts on the core nodes of each of our 50 sites the following load (each core site is serving 1.86Mio subscriber):

- 2.09T bit/s throughput (to/from RAN), same again to IP-backbone or inter-connect
- 171M packets/s

The transit traffic adds additional traffic to gateway sites since only 6 out of the 50 core sites have inter-connections to internet / application server:

- 15.3T bit/s additional transit traffic
- 1254M packets/s additional transit traffic

Note: Maximum packet size for application data is aligned to 3GPP to avoid segmentation.

Scalability in Performance and (Core-) Connectivity

The throughput and packet rates for a core site (see 7.3.1) are quite significant and change dramatically during next years. Their real development is expected also to vary in general due to appearances of today unknown services as well as they may vary from core site to core site. Only the largest available routers could scale up to that dimension and these perform routing in silicon. PDGs handle data sessions of individual subscribers (and more protocol layer and functions) and it will be difficult if not impossible to have for single PDGs the same scalability.

In addition, it is reliability realized on network level by setting up pools of (virtualized) network elements. This requires efficient load balancing between the resources as well as efficient directing of packets to the resource that handles actually the data session. These can be measures to handle fluctuation in local traffic demand as well as for realization of network based reliability.

The expected high variance of performance requirements as well as the management of resource pools (virtualized and/or non-virtualized network elements) makes it necessary to have:

- a flexible architecture using pooling (cloud computing like) and virtualization approaches;
- dynamic resource management, which is able to adapt fast to network (internal and external resource availability) and environment condition (serve temporary high demand but with lower level of over
provisioning);

- a flat architecture, especially as few as possible network elements in the traffic path (including avoidance of transit traffic)

Use of external resources to support operator network

Large portions of traffic, especially the cellular modem traffic (see 7.1) are nomadic and can be thus subject to offloading from operator core network and/or backhaul. LTE/SAE paves the way to connect non-3GPP access systems to current network architecture, which may ease the burden for the radio nodes and potentially for the backhaul. However, it does not necessarily lower the load for the core network. Nevertheless does this requires

- dynamic consideration of such resources in resource management and
- efficient configuration of the network, i.e. preferably self-configuration

Differentiated QoS Handling

The intention of LTE/SAE and foreseeable next generation of mobile networks is the support of all services including voice. The different services have often different QoS requirements, which might be realized by dedicated resources or by common resources that realized different traffic handling internally.

Dedicated resources in backhaul, e.g. leased line/radio link for voice traffic ensuring low latency and jitter and other resources, like DSL links, for services with lower QoS requirements such as latency/jitter. The use of multiple connections to the numerous radio nodes needs to be supported by efficient configuration and resource management, which performs the admission control.

The core network itself needs to be able to handle the services with different QoS requirements in an efficient way without excessive over-provisioning. A solution may include multiple queues in the core nodes, dedicated connection resources, e.g. via MPLS, dedicated routes and others. Since the traffic demand of services with specific QoS needs varies this need to be considered in the resource management based on operator rules, which may be dynamically updated to business and network situation.

Number of interconnects to other networks, e.g. Internet

The number of inter-connects to other networks plays a vital role in the core network dimensioning due to influencing the transit traffic, which has to be handled by the gateway nodes. This is caused by the having traffic endpoints outside the mobile network. Even traffic that could be handled locally (mobile-mobile voice or other P2P traffic) is always shortcut at the end of the tunnel endpoints or even outside the network.

The increase of number of interconnects can be expected and these may be even aside the radio node. This has several consequences:

- Increase of inter-connects does only take effect if the tunnel endpoint for a session is normally located at the most adjacent inter-connect. This makes the determination of the endpoint more challenging (network configuration) and suggest the shift of the tunnel endpoint due to long lasting sessions
- Having inter-connects adjacent to radio nodes (there are 1004 radio nodes per core site in our example above) required PDG functionality there with consequences for configuration effort including for resource management

Impact of measures to optimized user traffic handling (CDN, caching)

The foreseeable optimizations for specific services, e.g. a CDN for stored video, require service dependent session handling. This impacts rules for resource and admission control as well as network configuration. The effective integration of such service specific interconnect point is necessary to allow a dynamic and optimal resource management and effective network and node configuration.

Network Configuration Issues

The example network for 93Mio subscribers (see 7.3.1) has 50.200 radio nodes and in minimum 100 core nodes, which results in at least over 50.000 IP addresses. Not considered are control plane nodes, additional addresses due to redundancy, visibility of internal core node structures (IP address per internal component and not per node) and virtualization. So the number of addresses in a real network could easily increase to 100000 to 150000.

The clustering of the network in pools and adaptation of network configuration due to network (e.g. node failure) and resource situation (local fluctuation in resource demand) put high demand on network configuration and their dynamic update.

The interworking with mobile networks of the previous generations will complicate the network configuration even more.
7.5 Other Requirements

7.5.1 Wireless Devices and Requirements

The next generation wireless device will support a vast array of services with a powerful and complex communications engine. The radios in many devices already support cellular, WiFi and personal area networks. International roaming requires devices to support a variety of radios/bands because globally, the operating bands are not consistent. In addition, the major market split between TDD (India, China, etc) versus FDD (US, Europe) requires the device to support different duplexing options. As a result, the RF complexity in the device has increased drastically, requiring radios that will support many bands and duplexing methods.

In addition to the above RF scenario in the wireless device, the next generation device will support carrier aggregation and heterogeneous network operation where there could be simultaneous communication on multiple RATs. The wireless device will be equipped with and act as a gateway for a multitude of sensors. It will perform spectrum sensing for capturing and analyzing the radio environment. The radios will possibly even support flexible protocols. Any of the radios will be able to take on the role of cluster head or relay in addition to operating as access point or client or peer. The radios in the device will be performing local RRM and assisting with network RRM. The user may be simultaneously subscribed to multiple operators, offering complementary service features. Such a complex RF configuration in the device poses challenges and opportunities.

The wireless device will also be situation aware in that it knows and uses its own environment, the local environment and the broader environment. The device will be equipped with loads of memory and processing power; over the next decade, we may expect multiple orders of increase in the phone’s storage and processing capability. It will be capable of opportunistically loading and storing a large volume of information and performing complex processing tasks. It is likely that the wireless device will diminish the user’s need to own multiple devices such as laptops and DVD players. It is likely that the wireless device will appear in different form factors ranging from a wearable device to operating with a screenless display. The wireless device will be supported by hybrid energy sources and energy harvesting from the local environment.

7.5.2 Peripheral Ad hoc Networks and Requirements

The future Internet services will comprise of pervasive HD media services, 3D services, user-centric personalized services and novel M2M applications. In addition there is a general trend where cloud-computing services are becoming increasing popular for enterprise services (e.g. Software as a service (Saas) in Banking) and other user-services. These will inject a substantial additional data load to the future core Internet. Therefore, NG-Wireless network architectures have to consider such services in order to enable future wireless architectures to support these services. In addition, there is an opportunity for NG-Wireless networks to decentralize the provisioning of future services so that the load on the core network is alleviated. In addition, the design of NG-Wireless architecture has to consider the trends that will result from fulfilling requirements prevalent in the 2020.

For instance, the wireless networks have to sustain the forecasted throughput of 1Mbps per user. There will also be a higher population and consequently user density in future societies. The penetration rate thus indicates that the high number of mobile users will require high throughput per area in the range of $0.2\text{Gbps/km}^2-1.25\text{Gbps/km}^2$, also, it is important to respect the BS Tx Power Constraints in order to preserve a green communication environment. Forecasts have also shown that in dense regions, the BS density, in the range of $(22.5-112.6\text{site/km}^2)$, will provide hurdles towards achieving this. Whilst in rural regions, the higher BS Tx Power required coupled with the increased emitted radiation, may pose a challenge towards green communications.

However, there is an opportunity of using decentralized wireless networks towards a solution for the above challenges. Such wireless IP-based networks will be located at the periphery of and will be connected to core networks. Ad hoc networking does not require any centralized infrastructure for communication. Instead it permits the establishment of a completely autonomous and robust wireless communication paradigm by allowing cooperative multi-hoping packet delivery. As such, ad hoc networks can provide a localized autonomous network to provide location based or user-centric personalized services. Such services can be provided for home or citywide domains. Thus, the total data load is segmented among local communication domains however subject to the nature of the services provided. In addition, the proximity and exclusiveness of these networks to groups of end-users will enable “service providers” to provide the appropriate throughput, scalability and “low power-large area coverage” capabilities required for NG-Wireless architectures. These
networks can also be used as access network to Internet services where data are stored in the local neighborhood environment proactively based on user-defined requirements or requirements automated behavioral recognition patterns. This will help operators establish a more proactive traffic management strategy in order to improve service quality.

7.5.3 M2M Communication and Requirements

The wireless network may be improved to support large-scale M2M communication. A very large number of M2M communication terminals may be connected and managed by centralized servers. M2M communication includes Machine to Machine (M2M) communication and Human to Machine communication mode. The following related features need to be addressed in wireless network, including but not limited in these aspects:

- **Location Management.** Usually the communication device is deployed in a certain place or a certain area. In the future billions of devices will be deployed, while it may be desirable from a M2M application perspective to poll only a sub-set of all the devices in a specific area. For several M2M applications, devices are at fixed locations, which are well known by the M2M application owner. Therefore, it is not needed to store the location information of these devices in the network. But for many other M2M applications, the devices will be mobile, and the network still needs to support this. This would introduce special location management requirements.

- **Time Management.** The work status or method of devices may change in time. Also, for some applications the actual time at which communication takes place is less important, but low communication costs are extremely important. A network operator can offer lower communication fees for this type of applications by allowing communication to take place during low traffic time periods only. Possibly the network operator may want to dynamically adjust these time periods based on the actual network traffic load at a specific time.

- **Theft /Vandalism Vulnerable Control.** M2M devices are often located in remote areas and ideally are untouched after installation for many years. The remote locales make these devices more susceptible to tampering by unauthorized persons. The tampering is often accompanied by damage to the metering device. The security mechanisms of the network need to be improved to detect this activity as early as possible in order to deactivate the device’s service and the related USIM (User Service Identity Module).

- **Group Management.** Group based policing and group based addressing for communication terminals should be provided.

- **Mobile originated only service and infrequent mobile terminated service support.**

- **Priority Service.** Important and emergency data transfer should be processed first.

- **Multi-hop networking.** Large scale autonomous and distributed M2M communication may require the use of an efficient and effective distributed routing algorithm in order to extend the coverable distance for end-to-end communication. Thus, services such as automated adaptive traffic management could be enabled through the communications among sensors and smart traffic lights.

8. Key Features

8.1 RAN

Having elaborated on the requirements for the RAN resulting from throughput demands as well as the constraints for transmission power and radiation per base, we will now summarize the key features the RAN of NG-Wireless is supposed to offer in the future. The major characteristics of the RAN will cover a high degree of flexibility, efficient use of available radio resources and an energy-efficient operation at low operational costs. These characteristics are established by the integration of new technologies, in particular

- Spectrum reframing/aggregation
- Cognitive Radio / Software Defined Radio
- Beam forming and distributed MIMO
- Interference mitigation and management
- Cooperative radio resource management
- Self-organizing network (SON)
- Multi-standard single RAN platforms
• Cooperative Relaying
• Energy efficient technologies

Suitable integration of these technologies within a consistent system architecture will enrich the RAN by the following functionalities and features:

• Improvement of the signal conditions for cell-edge users
• Guaranteed Quality-of-Service classes for any user at any location
• Low latency
• Techniques using white space TV bands
• Spectrum aggregation for efficient signal transmission in fragmented frequency bands
• Support for heterogeneous networks, enabling seamless vertical handover between different RATs
• Coexistence of different systems in the same frequency band
• Self-management and self-healing processes, decreasing the effort for maintenance
• Active energy management improving the power dissipation of the entire network

In addition to the functionality provided by current architectures, the NG-Wireless RAN will offer the following innovative key features:

**Dense Small cells**
- Interference is mitigated through dynamic spatial/beam path selection
- Hierarchical cell structure with separated user plane and control plane
- Distributed radio resource management
- Backhual bandwidth saving by traffic offloading and local contents caching

**Cloud computing based distributed RAN:**
- Largely lowering the cost of BBU with cloud computing architecture
- Maximizing system capacity by joint processing signals from distributed Antenna
- Load balance between Virtual BS Clusters

**Mobile Cooperation**
- Mobile terminals act as relay nodes or establish a direct air-link to enable P2P transmission
- Increasing system capacity without infrastructure cost increased

**Self-organizing networks**
- Self-managing and self-healing processes: reliable and robust operation required
- Managing the resources and maintaining transmission links in wireless meshed networks

**8.2 Core Network**

The NG-Wireless network architecture aims for energy-efficient operation through an architectural redesign that takes energy consumption as a prerequisite of efficient operation not an after-thought and enables collaborative business models through

- Infrastructure sharing which will become more common as “open access”-related and other regulation concerning rural areas in Europe and elsewhere becomes more prominent and likely expands to other domains
- Unbundling of access network as well as generic functional domains (application, security, authentication, charging)
- Interworking of local, regional, and global providers in addition to community and privately-owned networks.

At the core of NG-Wireless lies a service- and network context-aware architecture, which benefits from automatic and dynamic management of network resources based on the current network conditions.
NG-Wireless aims for an architectural redesign that enables energy-efficient operation based on rethinking the key choices in legacy infrastructure, including energy considerations at the device and the network; accommodating the foreseen traffic patterns and denser deployments; and (re)developing part of the protocol stack accordingly.

As a complete architecture NG-Wireless ought to cover the following areas:

- Access Control and Subscription Management
- Mobility Management
- Routing and Transport
- Resource Management (Radio and Core, including SON and QoS mapping and policing)
- Network Management (including SON)
- Charging and Accounting
- Data integrity, Privacy and Security
- Lawful Intercept

From the viewpoint of wireless network, it is recommended that the following requirements and challenges may be considered:

- Very large number of users (due to M2M);
- Vast traffic volume increase (x10 system capacity of LTE);
- Optimization for video based services (for example, optimization for multicast transport, support network coding, support P2P video transmission, support video codec/rate adaptation, etc)
- Support cloud computing based network service (for example, load sharing and load balancing, fault-tolerance, etc)
- Supporting circuit emulation (for legacy CS domain services over EPS access)

In addition to the functionality provided by current architectures, the NG-Wireless Core Architecture will offer the following innovative key features:

- **Modularization of generic network functions** for service provisioning, such as security, roaming, charging and accounting, access control and subscription management
- **Cognitive network management and operation**:
  - Adaptive mapping of, on the one hand, user requirements onto services offered by the providers and, on the other hand, resource assignment according to operator strategies and user preferences
  - Situation- and context-aware real-time monitoring and reporting of resource status (temporal and geographical area based), and automatic evaluation of the resource situation (based on current resource utilization)
  - Autonomous decision-making and optimization (based on control-objectives) of current and short-term future resource usage, and re-assignment of resources as needed
  - On-demand self-adaptive operation and control-plane functionality, including proactive identification of spare resources
- **Optimized traffic handling** based on the service characteristics and topological knowledge while adhering to operator and end-user preferences:
  - Network-based, access-technology independent network selection, admission control and QoS adaptation mechanisms
  - Design and development of resource discovery across operator domains using on-demand SLA to create dynamic virtual networks
  - Energy considerations at the device and the network counterparts
  - Traffic path/interconnect, caching, and designation of dedicated resources for specific services
- **Next generation mobility management** featuring:
  - Consolidated mobility paradigms and protocols between different networks and end-devices, based on a two-dimensional flattening of the MM architecture. On the one hand, reduce the network elements involved in MM and, on the other, decrease overlapping functionality across the protocol stack
  - Basic seamless connectivity as well as the design and development of on-demand, self-(re)configuration mechanisms, pro-active identification of backup resources, optimal resource usage and self-healing is in-scope
Automated user-centric network selection strategies, including educated handover strategies between different types of networks

- **Automatic and dynamic SLA negotiation and realization** (i.e. provisioning) in multi-administrative domain environments, which includes:
  - Filling in of pre-existing contracts through intelligent negotiation processes between infrastructure providers.
  - Automatic inter-working between local and global network, operator-provided (akin to current cellular networks) and user-provided and community networks (such as FON and municipality networks).
  - Establishment of on-demand network federations for service provisioning. Federations can give new meaning to ownership in both high-level business entities as well as low-level network infrastructure.

9. Summary

This document has presented the vision for NG-Wireless in 2020. The document has summarized the key environmental constraints that current and future network architectures will face, in particular in regards to deployment density and throughput requirements. The document has then reviewed recent developments in the business aspects of modern telecommunication networks and provided an outlook with respect to future trends. A key message is that vertical and horizontal value chain splits have been in the works for some time and this trend is expected to further gain momentum, thus creating several new opportunities for old and new actors in the field.

This document has also presented an analysis of current and projected traffic patterns, with respect to traffic composition and throughput requirements both at the core and at the RAN. For the latter, NG-Wireless aims at introducing new technologies that will deliver 20x more throughput and capacity than LTE-Advanced. For the former, NG-Wireless aims for a new architecture to handle the projected 1000x increase in throughput, with a more flexible design that can cope with unpredictable demands more intelligently. Overall NG-Wireless will have to accommodate at least an order of magnitude more terminals than current expectations.

This document has also included a high-level description of the services we expect to deploy by 2020. These include, among others, pervasive and 3D multimedia, application mobility, personalized services and user-centric communications. M2M applications (smart cities, grids, eHealth, and environmental monitoring) are also foreseen to play a major role in future networks. Last but not least, this document has listed the key features that NG-Wireless will deliver.

To reach these ambitious goals NG-Wireless will base its design on five pillars, namely virtualization of network functionality as well as of computation, communication, and storage resources; modularization through generic self-contained building blocks that increase operational and management efficiency; cognitive network operation at the core and the RAN; content-oriented networking and peripheral decentralized ad hoc networks.

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11. Appendix: Technical Challenges & Requirements

11.1 RAN Side

Based on the above analysis on the challenges of Vision 2020, we should have the following design target and basic requirements for novel RAN architecture in NG-Wireless program:

- **Micro Scenario**: Micro or Pico BTS or RRU on street lamp poles, below 10m
- **Capacity**: Support average areal throughput more than 25 Gbps/km2 (excluding WLAN/Femto)
- **Coverage**: Outdoor scenarios (including car, excluding indoor)
- **QoS**: 70% Video/Audio traffic, mobile Internet access, numerous M2M access
- **Heterogeneous**: Smart pipe selection & seamless handover among different RAN pipes
- **Flexibility**: Support new business models of operators
- **Cost**: Low (limited by expected revenue of operators, decided by comparison of solutions)
11.2 CN Side

Multiple access technologies: NG-Wireless RAN as a core technology, but other wireless and optical technologies will also be in place. Carrier-grade WiFi is as an example for offloading.

Energy efficiency emerges as a key research topic alongside “classic” performance metrics (throughput). Virtualization of resources leading to automatic and dynamic SLA negotiation and realization in multi-administrative domain environments.

Content-orientated networking: High densities translate into many people carrying device(s) with several GB of storage capacities. With local area network and contents resolution and delivery systems a significant part of the traffic can be offloaded from the cellular infrastructure.

Cognitive network management.

Trustworthy communication which includes ID management and NG-AAA.
Imprint

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