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Expert Working Group on

Mobility/Connectivity and Networking Layer

White Paper

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List of Acronyms

2G	2^{nd} Generation
3D	3 Dimension
3G	3^{rd} Generation
4G	4^{Th} Generation
5G	5^{th} Generation
BSD	Berkeley Software Distribution
BYOD	Bring Your Own Device
CDN	Content Delivery Network
C-RAN	Cloud-Radio Access Network
D2D	Device to Device
GEO	Geostationary Orbits
ICN	Information Centric Networking
IoT	Internet of Things
IP	Internet Protocol
L2	Layer 2 of Protocol Stack
M2M	Machine to Machine
MAC	Media Access Control
MP-TCP	Multi Path-Transport Control Protocol
Phy	Physical layer (of protocol stack)
QoE	Quality of Experience
QoS	Quality of Service
SatCom	Satellite Communication
SIM	Subscriber Identity Module
UE	User Equipment
UNI	User Network Interface
V2V	Vehicle to Vehicle
V2X	Vehicle to Infrastructure
WiFi	Wireless Fidelity
WSN	Wireless Sensor and actuator Network

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Executive Summary

This document summarizes the work of the networking community related with networking aspects, covering mobility and connectivity as well. This work, which should be considered a part of the large on-going efforts on the design vision of future networks, presents some of the key trends identified inside the community as essential components for a sustained research space in 5G networks. Here, 5G networks are seen not only as "better, faster" networks, but as networks with added functionalities, bringing concepts currently on the service layer embedded into the network fabric, in order to be able to provide the most efficient service at the minimum cost (and energy) and high reliability.

Amongst the areas identified as critical, one should highlight: novel network architectures, including highly flexible connectivity and localized wireless and wired; new interfaces and abstractions towards the network, coping with diversity of requirements as video streaming and M2M communications; social aspects and renewed visions on satellite usage; better management frameworks, potentiating effective service development and deployment, and integrating security, privacy and trust.

In general, the perception is that the future network should be increasingly more diverse, complex and able to cope with very different scenarios, and with very large heterogeneity.

1 Rationale

Communications has become embedded in the society fabric. In particular, mobile communications is now the technology in realising the fully connected society. It is not strange, though, that we are witnessing an explosion of wireless connectivity, and of different ways to optimize it.

The space diversity strategy (with heterogeneous networks) is now an expected evolution for increasing wireless capability, often associated with ideas of centralized solutions (C-RAN) for handling the increase complexity and interference issues (see Fig. 1). This brings significant challenges on how mobility, and connectivity in general, is addressed. Heterogeneity is currently achieved through multi-tier architectures (a mix of macrocells and smaller cells), and (ii) the coexistence of different wireless technologies, e.g., 2G/3G/4G, WiFi. As a further aspect, a User Equipment is expected to be able to communicate in a device-to-device (D2D) fashion (or in an edge-path approach). Such D2D links could be established on license-exempt bands but under the control of the cellular infrastructure (or not). As a result, users will soon have several and different connectivity opportunities to exploit. The heterogeneity dimensions will be further enhanced by the expected increase in the simultaneous usage of different control platforms, with users dynamically switching/simultaneously accessing different connectivity control platforms.

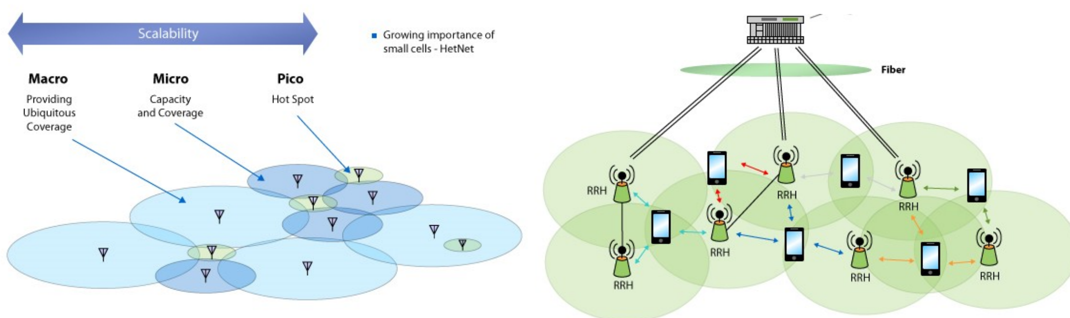

Figure 1 Changes on the wireless cell concept

Smart Cities, Smart Buildings and Smart Grids are popular applications of the Wireless Sensor and Actuator Networks (WSN), recognizable as essential for the future society and digital economy. These are examples of M2M (Machine to Machine) paradigms where devices equipped with wireless interfaces, talk to each other with the purpose of automation and control of industrial processes. Two M2M paradigms, , based on the number of M2M devices and expected cost of the communication, are normally proposed in the scientific community: the cellular M2M approach where machines have a SIM card and are connected directly as UE nodes to the RAN; and the capillary M2M approach where nodes use a short-range air interface (e.g. Zigbee/802.15.4) and realise a network architecture similar to the one used in WSNs, forwarding measured data to the Web though a gateway functionality.

Thus different sets of challenges are coming from the diversity of applications that we are now expected to support: from low bit-rate, very low power, sensor applications, to very low delay of highly interactive augmented reality, and high definition of entertainment video. Furthermore, communication resources (well defined Quality of Experience) may need to be guaranteed for some applications. All these bring distinct challenges to mobile communications, and, if their diversity of requirements is already challenging for a cabled network, they become an impressive obstacle to overcome in wireless communications. Note that in current networks there is not really any element that is able to cope with the wide diversity of the traffic generated by so different traffic sources.

The challenges that we have to overcome from a connectivity view are intrinsically associated to the physical, economical and even administrative constrains we can expect in this environment. We can expect to face the following non-technical trends:

- Increasing diversity of optimized wireless solutions (to different application domains)
- Increasing diversity and number of connected devices, and associated diversity of traffic types
- Increasing pressures for low cost operation
- Increasing diversity of actors (in terms of the overall application domains, and how these are structured in terms of business)
- Increasing pressures for multi-polar solutions, where the administrative entities involved in a communication path will be very different (potentiating different sharing models of infrastructure)
- Increasing requirements for critical, secure and reliable communication, including requirements for data protection and privacy topics (as consequences of trends as BYOD, Mobile Sensing, Open and Big Data, Connected Cars, etc.), while supporting public safety and disaster relief (PPDR) operations
- Increasing requirements for higher user control
- Increasing dynamicity of networks and of network(s) used.
- increasing requirements for energy efficiency

All these trends will have their toll on the connectivity solutions we aim to address. In order to advance these trends, there are several areas that need to be carefully investigated – in some cases per its-own, in others integrated in overall solutions. In the end, a 5G network must be able to respond efficiently and trustable (including security aspects when needed) all the time (the network will need to be robust). The communication paradigm should be smart (as intelligent as possible in terms of decisions on the communication) easily manageable (homogenous control mechanisms as much as possible) ubiquitous (perceived as always available) and on-the-need (when communication is required, even before it is needed explicitly).

The simpler requirement we have for the 5G network is that will be "better". Better in terms of bandwidth, latency, dimension (size), energy efficiency, connectivity and management.

The 5G network will be able to provide broadband location-independent access to places like planes, high-speed trains and ships. It will be able to optimally explore the underlying L2, and will use the existing context to provide energy efficient communications. This means that 5G networks will be multi-technology – not in the sense that resort to different physical layers, but that they can resort to different networks as well, either from the point of view of technology or of administrative ownership. As a sentence, the future 5G network can be considered a "not always all-IP network", bringing the advantages of other network architectures to the cases where they may provide value over IP-only systems (e.g. ICN, Zigbee, etc…). The network will also be inherently multi-tenant, in order to be able to explore the technology diversity that will exist.

In some aspects, the networks (or some network nodes) will need to be seen as intelligent “computing & storage” entities, bringing different features into the network realm, where some concepts that were until now on the service layer are integrated, enabling the synergetic development of network functions based on software engineering principles (thus lowering the product development costs).

The 5G network thus brings to users not only better performance, but also new functionality. Its scope is not limited to the radio access, but encompasses the whole network, including aspects as subscriber management, core network and transport features. Key technical requirements of the new network vision will need to include some well-understood aspects on the research community, but have not yet reached widespread adoption:

- Global identifiers for users and services, independent from specific technologies of communication entities and of their current location
- Coexistence of different networks, not necessarily IP-based
- Integrated and efficient interaction between the wireless domain and the backhaul.
- Multi-tenancy, and more than that multiple modes of administration.
- Support of unlimited seamless mobility across all networks/technologies
- Support of tailored and adaptive services and QoE
- Built-in capacity of evolution and adaptation, allowing a transparent migration from current networks and permitting future developments

2 Research priorities

In this global sense, many traditional research areas still remain as priorities and are needed to continue in the future. Nevertheless, there are a few aspects that should be specifically highlighted as important and strategic to consider.

Novel views on network architecture

To meet these technical requirements, the 5G network needs to adopt a name-oriented architectural framework in which communication takes place among entities identified by names, without a static binding to their current location. Names must be used to identify all entities involved in communication: content, users, devices, logical as well as physical points involved in the communication, and services. With the ability to communicate between names, the communication path can be dynamically bound to any of a number of end-points, and the end-points (both source and destination) themselves could change as needed. Note that this is a challenge that must be extended across multiple types of technologies from IP to other Future Internet approaches, from systems web-oriented to systems relying on L2 switching.

The separation of identifiers (names) and locators (addresses) provides well known advantages. Current technology already allows for the deployment of a cleaner architecture that decouples the internetworking layer from the service layers, but research is needed on how to perform migration from current architectures to more efficient technical solutions.

Such solutions would allow named-entities to be mobile; should enable them to be reached by any of a number of communication primitives; should allow the pushing of information to a specific set of receivers based on name; should allow choice of the return path independent from the forward path, should support source/initiator mobility and choosing the path at the time the data is sent rather than at the time when a subscription was made (without needing to maintain a state in the network for the reverse path); should allow communication to span (simultaneously) networks with different technologies (e.g. exploiting also multipath protocols) and allow for disconnected operation. Furthermore, the communication path must be able to be dynamically bound to any of a number of end-points, and the end-points themselves can change as needed; in this sense the whole network will rely on views very akin to opportunistic routing: instead of choosing known routes, mechanisms that decide the next hop dynamically upon link emergence will be common.

Highly Flexible Connectivity

The current heterogeneity of networks and technologies implies that new protocols and layers should be devised or adapted from existing standards in order to ensure a transparent and seamless end-to-end connectivity between services (sensors, user terminals, cloud services...), including defining the communication model to use (unicast, broadcast, muticast, D2D) .

Network functionalities for dynamically handling network connectivity in a flexible manner as operational conditions vary (e.g., propagation conditions, user positions) need to be developed. Of particular importance will be device and link discovering and pairing. For on-need connectivity, the current pairing times need to be substantially reduced, and devices need to have fast mechanisms for device discovery.

Novel connectivity algorithms to determine the best connection opportunities for users based on the requested service will need to be developed, along with the mechanisms to realize and to dynamically adapt the connectivity in an efficient manner and without affecting the end-to-end communication, especially considering that some of the interfaces involved may not be running IP-protocols.

Local wireless and wired wireless

Energy considerations and resource optimization will be two important features that 5G networks must comply with – and the diversity of transmission modes, to be expected, require intelligent perception of the localised communication domain. Integrated localisation schemes will be key enablers to communication management and for many new services in 5G. Localisation (and specially neighbouring) can be used to for example relocate video service provision server in the backhaul; or to select the best interface for communication, resorting to cellular or D2D as adequate; or to perform multi-domain network breakout operations. This will become increasingly important with the increasing number (and diversity) of cells.

(There is a need for D2D proximity capability where terminals can communicate directly and without support of a backhaul network. This can be in terms of specific need, range extension or temporarily in a time of outage or adverse conditions.)

However, for such approaches to be efficient, highly improved interactions between the wireless segment and the backhaul network are required, both in terms of performance, complexity (e.g. selecting which traffic to steer, and when) and administrative flexibility (crossing operators). Harmonization of processes is essential here (harmonization of authentication and authorization, harmonization of QoS, harmonization of network views: local data path, short data path, core data path).

The software network: Interface abstractions and layering

In a multi-technology, multi-connected, multi-tenancy network such as is being envisaged for 5G, flexibility, programmability, dynamic reconfiguration and dynamic resource allocation (spectrum, bandwidth, networking technologies, …) should play a central role. A major goal should be to improve – with respect to the existing situation - control capability on the part of infrastructure and service providers, context- (and, in some cases, content-) awareness in carrying out the actions required by a service, users' Quality of Experience (QoE) and, last but not least, time-to-market service offerings and their deployment. The last point requires easier and uniform interaction (through more powerful and content-rich APIs) of developers with the network and with providers of networking services.

Achieving flexibility and programmability can be fostered by different architectural choices: i) a more aggressive use of virtualization to implement network functionalities; ii) improved control capability, by decoupling the control and data plane and acting on flows at different granularity levels; and iii) usage of software engineering paradigms for simplifying the development of features as network function placement, load balancing, high availability and exception cases handling.

Thus, the diversity of networking scenarios inside 5G networks are such that serious attention should be paid to architecture design interfaces. For full exploitation of flexibility, it is essential that different parts of the communication path can be redesigned and repositioned. It is clear that relying on the often misunderstood "All-IP" concept is not enough to address the complex challenges for deployment of scalable and reliable networks. Interface abstractions, from the user (e.g. metadata to signal application requirements, or some other improved UNI that is able to supersede the basic BSD Socket Interface), network control and service development side, are essential for such dynamic environment. The diversity of situations for M2M communications (continuous connection? Intermittent network? Low bandwidth reliable? Health safety monitoring?) clearly illustrates the radical changes we need on our visions of device-network signalling. On a different view of the same issue, 5G networks will need to develop a clear view of network layering, in order to foster the complex ecosystem we expect. As IP increasingly loses its claim as universal data and control protocol, a new layering structure will need to be found.

Furthermore, such decoupling strategies significantly increase the chances of developing an environment that fosters quick and efficient contributions from various members and obviously from very, and many different networking areas. It will promote evolutionary approaches to network deployment, and will potentiate the usage of virtualization techniques to network deployment, and facilitate federation of networks and services. Deployment of novel network features is an area that will need to be globally researched, and which can be facilitated by proper interface design.

The developments in C-RAN also bring similar problems. The basic concept of cloud-RAN is to separate the digital baseband processing units (BBUs) of conventional cell sites, and move the BBUs to the "cloud" (BBU pool or BBU hostelling) for centralized signal processing and management. For different scenarios of the C-RAN architectures, what is the optimum position of the base band pool and where can be placed? Is it near the central office, or close to cell sites? And what are the interfaces (and which functional decomposition) that should be imposed in these different scenarios?

Research is needed to understand what should be the best interfaces and protocols for internetwork and service control and management. (e.g. an API for the application for transmitting their requirements hiding all items which are to be processed under an "intelligent adaptation" of the network?)

Social as a network element

A large explosion of user-centred devices is expected in the next years, with increasingly connected human-owned devices. As a result, their traffic will inherit social behaviours. Things will move, or generate data according to "social" patterns (i.e. space-time correlation of data generated by things). Exploiting the knowledge about this social behaviour can bring many benefits from the technological viewpoint, such as for example:

- Interference prediction and coordination techniques at PHY and MAC layers
- Traffic pattern prediction useful at MAC scheduling and RRC level
- Content sharing techniques applied to D2D concepts
- Opportunistic routing in multi-hop networks
- Customization based on the QoE requirements (i.e. not to give more network resources than needed but also not less).

These advantages in terms of better exploitation of network resources provide an opportunity for novel views on network design and control. Tailored QoE should be a usual ability for the system management, potentially context-aware (in function of the user/social aspects/application/service).

Satellite renewed

The integration of satellite (GEO and non-GEO) and terrestrial can be used to extend the 5G network to ubiquitous coverage. For example to sea—cruise liners and yachts, to passenger aircraft, trains and even to remote locations such as holiday villas. A simple example is via backhauling but this can be done in an intelligent manner by routing traffic either over the satellite or terrestrially depending on the content and the required QoE.

Satellites have been traditionally used for broadcast purposes but as CDNs become common, the ability of satellites to download high data that can be cached for onward delivery becomes an attractive feature. The interplay with new (inter)network architectures, such as CDN is important to consider for SatCom/cellular integration. Pervasive caching and naming of information and content transferred over the networks would more easily allow the inclusion of SatCom into an integrated Satellite-Terrestrial network by exploiting the broadcast/multicast and broadband capabilities and masking the longer propagation delay, improving overall performance with caches at the edges.

Three other areas where satellites may have a large impact, and will lead to a reinvention of the way they are used, are:

i) IoT coverage to wide areas involving sensors and M2M connections are ideal services to make use of satellite wide area coverage. (The challenge is to design efficient low data rate communications in large numbers via the satellite);

ii) Transport services including V2V and V2X are again ideal for satellite with its wide coverage (e.g. for safety information).

iii) Global localization and earth data information, which already is achieved by satellites, and can be integrated in novel services for sensing functionalities. Future 5G system will include the integrated provision of communication, localization and sensing on a global and very accurate scale.

iv) robust, virtually infrastructure-less network for safety and emergency networks, highly distributed enterprise networks and backhaul alternative for isolated and remote areas

Security, Privacy and Trust

Security and Trust are conditions which will need to be supported by 5G network. Security solutions for assuring integrity, privacy and access to information are challenged by emerging data protection legislation and simply the human desire to produce, own, share and control information. Often, data exchanged is expected to include information from several critical services such as emergency or medical information that must have full network availability as well as security and confidentiality protection measures. These vectors are transversal across areas, and need to be supported in all research aspects. It is worth to note that the diversity of scenarios considered will unavoidable imply that the trust guarantees of future network providers will vary greatly, presenting network designers with a completely different scenario for trust establishment. Countering anomalous dysfunctional and/or malicious activity is of key importance for assuring the protected operation of the network and maturity of the components from which it is constructed.

Furthermore, BYOD and mobile sensing based on common smartphones brings new possibilities for using mobile devices to gather data about users and, as consequence, about the world or some specific circumstance. The usage of mobile phones as means to collect and analyse behaviour patterns of individuals and environment in order to understand how events affect their behaviours and, consequently, how potential events can be automatically detected starting from data collected by a number of users, poses specific challenges as open and big data issues may improve network and service delivery, but user privacy needs to be balanced in this process.

Trust establishment is currently rigidly defined, and largely centralised. As networks become more capable to operate at the speed and agility of a person embedded within their online virtual and pervasive world, It is required to have trust relationships to largely map the changing trust environment of the people and enterprise using that network. This begins to move away from secure network transactions and more towards the information itself being implicitly secure, hence supporting the changing sensitivities of the information and the impact that information has on those making decisions based upon that information and the effect on the real physical environment. New techniques such as Identity Based Encryption (IBE), Attribute Based Encryption (ABE), functional encryption and fully homomorphic encryption offer new solutions which should be addressed from the start. New key management techniques are of primary importance here.

Effective Service Development and Deployment

5G networks call for successful handling of many and demanding requirements. This has a major impact on service development and deployment, bringing specific challenges to proper application provisioning. It is important to stress on the following requirements:

***Rapid, easy and dependable application/service deployment*:** Rapid service deployment is needed in order to follow the rapid pace of changes of services and applications. Aspects as faster conformity testing, and automatic seamless handover to an updated system are essential in this context.

Intelligent adaptability to varying conditions: The guarantee of high QoS/QoE levels that will be relevant to the deployed applications/services (corresponding to a certain level of service availability, performance, reliability, and usability) will need novel and intelligent approaches to lead with extremely varying networks.

Huge scalability support: We will need to support proper application provisioning in very demanding and changing contexts of operation, e.g., 1000x capacity increase in 10 years with billions of users and trillions of machines/things. System consolidation is also an issue, as extreme diversity may lead to unmanageable service requirements (provisioning 1000 devices with the same firmware is much less complex than provisioning 50 devices with 20 types of firmware).

Agile Management Frameworks

A powerful (self-)management framework is necessary in order to achieve optimality in 5G systems and meet strict usage and development requirements (e.g., acceleration of deployment, high QoS/QoE, proper application provisioning in demanding environments, lower cost of the infrastructure, cost and energy efficiency). Such a system may rely on traditional components of management frameworks: (i) data and context acquisition; (ii) fast immediate automatic adaptation, to maintain system operation; (iii) analysis and learning, to guarantee continuous optimum performance, and (iv) decision making, to select the most important aspect at a given time. Nevertheless, higher degrees of intelligence, adaptability and self-management are expected. A problem that will be compounded by the need for multiple management systems to negotiate and agree in stable operation points.

This approach requires network architecture capable to enable network-wide observation and sensing (beyond spectrum occupancy, and including quantities such as protocol parameters and state variables, traffic, channel statistics, transmission and error events, interference, human behaviour, and so on) as well as data collection from various layers of the protocol stack. In this architecture, communication nodes shall perform sensing and data collection, as well as dissemination of appropriate information, in order to achieve situational awareness through sensing, model-building from new data and situations, and exploitation of past experience to plan, decide and act. Furthermore, all these actions may have to be performed with strong energy efficiency considerations in place. Future 5G network should be highly energy efficient without compromising the expected user quality of experience, and the above aspects of self-network management, covering variable topologies, device reconfiguration and intelligent setup functions have to be enabled in the network.

For instance, context acquisition can target the monitoring of contextual situations as soon as they are created. Contextual information includes the traffic, mobility and radio conditions. The output can describe the contexts encountered with respect to the aforementioned parameters, as well as the likelihood of encountering similar contexts in the future. Learning mechanisms can then target the development of knowledge regarding the handling done to encountered contexts (e.g., system configuration applied), the potential alternative handlings, and the respective efficiency of each handling. It can rely on reinforcement learning techniques. Finally, decision making will be responsible for the designation and execution of optimal solutions in order to handle specific situations (e.g., which cells are capable of providing extra capacity when needed etc.) according to the specific contexts encountered, in conjunction with the knowledge built from previous, similar handlings.

As another example, the network shall be able to recognise a data flow generated by a user that is watching a video streaming while commuting by train from office to home. By exploiting the context information, the network management system proactively distributes video chunks to the servers along the path followed by the train, in order to guarantee that the required video sequence is readily available from the closest server as the train passes by. Furthermore, the network management system may temporarily increase the data transfer rate before predictable connectivity holes (e.g., when the train enters a tunnel), in order to buffer enough data for overcoming the outage period. Furthermore, recognizing the type of video content, the network is capable of determining the source encoding that guarantees the best QoE to the final user depending on the current conditions of the connection, and to selectively drop the enhancement layers that cannot be delivered.

3 5G Network Evolution Roadmap

Timeline / Technology	< 2015 Features	<2020	2020+ Features
Network heterogeneity	• Independent networks • Integration at the level of interface selection in the terminal • Hard to switch across administrative domains	• Standardisation • Integrated mobility management of multiple technologies at network level • Prototypes on Coordinated multi-owner networks	Deployment of integrated multi-technology networks
Agile Management	• Proprietary solutions per operator and services provider	• Standardised interfaces • Prototype Integration with sensing, service and reconfigurable networking infrastructures	• Novel service and management frameworks • Commercially deployed
Satellite	Applications of integrated satellite and terrestrial systems for remote locations	Satellite and Terrestrial Integration at network and service levels	Satellite a component for content dissemination and ubiquitous connectivity

4 Summary

Network connectivity is an important aspect of future 5G networks, that will face a much larger diversity of considerations than in current 4G networks. Diversity, and intelligent control, are the two key vectors to overcome. Diversity of communication media, of scenarios, of traffic sources, of operators, etc…, are key factors for the future environment. To overcome this diversity increasingly more intelligent control(s) are needed for the network, providing all the required on-the-need actions for achieving optimised connectivity.

5 Recommendations

In general, three major research recommendations can be immediately put forward:

R1) Reorient traditional efforts to target significantly more complex, diverse, and unstable scenarios

R2) Launch efforts for increased network heterogeneity, looking for (meta-) architectures that can be evolvable, while retaining optimal advantages of existing solutions under control of different operators.

R3) Develop scenarios where the control and management planes are increasingly complex and aware of user and network context, including tailored network behaviour per user and device.