Wireless@KTH

“Wireless Systems for the TERA Age”

Research strategy
2015-2017

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Introduction

The overall aim of Wireless@KTH is to be an internationally leading research facility in “Mobile Systems for Mobile Services”, which together with researchers at KTH and its industry partners, is capable of developing this key area for Sweden and the Stockholm area. The Center provides neutral ground where world class engineers, representing commercial and industrial life, can meet senior academic researchers and students and engage in joint long-range basic and pre-competitive research projects, thus developing new ideas for wireless systems and services, and creating a basis for the wireless services and applications of the future. The key components of Wireless@KTH are:

- **A world leading consortium of active partners**
  A world leading consortium of industry and academic partners covering all crucial areas of expertise relevant to the target area.

- **A vision driven research program**
  - the tools to identify research issues and technology bottlenecks of tomorrow.

- **A hub for innovation in Wireless Technology**

- **A Project House – achieving critical mass in research:**
  Wireless@KTH plans, organizes, co-funds, and leads joint projects between KTH researchers and industry partners.

- **A magnet for guest researchers**
  an attractive guest researcher program – attracting the best researchers in the field.

- **A strong brand name**
  Superior visibility on the web - more up to date and better access to publications.

- **An informal meeting place**
  Seminars and workshops (or just informal get-togethers) are arranged to create a forum for discussion and debate. An interactive website creating a community of researchers interested in the focus topics, creating high visibility worldwide.

- **A center providing value** to its partners in terms of knowledge, research results and innovations.

The unique selling point of Wireless@KTH research is that it targets important strategic and structural system issues related to future wireless products and services in the 2020-2025 time frame. The overall positioning of the Center’s research can be summarized in the following motto:

**“WIRELESS SYSTEMS FOR THE TERA AGE”**

- USER EXPERIENCE AND THE NEXT 100 BILLION CONNECTIONS

While university research *should* focus on problems in this time scale, the fragmentation of research resources in many universities forces research groups – to achieve sufficient scientific depth – to deal with very specific problems with little insight into larger scale, structural problems with wireless systems. For the same reason, the ability to address problems that require cross-disciplinary competences and approaches is also limited. Even many of the EU Framework projects have a tendency to place too much emphasis on short-term development of various technologies, often within a single research area. *Wireless@KTH* will use a vision driven approach for its research (see figure 1). Using previous work in the Wireless & Mobility Foresight projects and other input from industry partners, a positive yet plausible vision of the future is developed.
The approach identifies several new technical, economic, and regulatory research challenges that need to be tackled to reach the vision. These challenges are mapped onto the competence of the participating research groups and industry partners, who jointly define research projects to question, investigate, and solve problems directly related to these challenges and the vision. Results in terms of publications, innovations, demonstrations, and skilled people feed back to revised visions of the vision. Developing and maintaining the vision driving the research activities of the center is a key activity of the center.

In the approach above, the Research Strategy, i.e. the description of which challenges and research areas the center should focus on, and how they are connected to the vision, plays an important role. The Research Strategy document is maintained and updated in two types of modes: major revisions (8-10 year cycles) that require revision of the long-term visions by means of explicit foresight activities (e.g. Wireless Foresight\(^1\), conducted in 2001-2002 and Mobility Foresight\(^2\) conducted in 2010); and revising the “grand challenges” and minor revisions (3-4 year cycles) where the focus is mainly on the research areas. The current document describes such a minor update.

This document is organized as follows: In chapter 2 three scenes from day-to-day life in 2025 illustrate some of the key challenges that the wireless systems industry faces. In chapter 3 the Mobility Foresight study is further developed into a number of techno-economic scenarios that in chapter 4 and 5 are developed into focus areas for research. Finally, Chapter 6 constitutes the research plan that summarizes the research challenges, and outlines the high-level research activities of the Center in 2015-2017.

Life in Rebecka’s connected world

“OMG, check this out! I’m totally sharing this.” Rebecka leans over to show her phone to her dad. He nods slowly at the screen when the soccer ball slams into the back of the net behind the goalkeeper. All in slow motion and from three different cameras in the arena, edited together by Rebecka on her smartphone.

It’s Swedish soccer sensation Zlatan who calmly finishes the game, upping the score to 5-0. The crowd of 30,000 unite in a roar heard miles away. Most of them have been watching the game as much on their smartphones as on the field. Every player is followed by his own camera, some of them are even wearing cameras. Other cameras zoom in on the crowd, many of whom are cheering with one eye on their screens.

Rebecka’s dad cannot help losing himself in the moment. Remembering when he tried to watch games like this on the subway. The cell phone screen kept on displaying “Buffering”... and all he got were blurry stills.

Now, every time a clip is shared, it’s being commented on as well as voted for. There’s a great prize for the fan that shares the most popular clip: a personal meeting with the players before the next game. Rebecka has eagerly been voting, commenting and sharing her own edits throughout the game.

She took a short break when the snacks arrived at their seats – snacks that were ordered and paid for with the arena app. Her dad also threw in a treat: a new team shirt that she immediately put on.

When the referee finally blows his whistle, a couple of hundred fans charge the pitch, cheering and waving their glowing cellphones. Her dad lifts his head and pockets his phone.

“Time to go, sweetie.”

She looks for the nearest exit, grabs her dad’s hand and they push their way through the crowd. Many of them are still in their seats flipping between reruns of the more spectacular goals and free kicks.

The subway trains are running as if it were rush hour following the increased mobile traffic in the area. When Rebecka takes a seat with her dad, her cell lights up with a message: “Congratulations, your clip won! Welcome back next week to meet The King of Soccer: Zlatan Ibrahimović.”

Challenge: We need 1000 times the capacity of today to enable people to share experiences

Rebecka’s night at the game illustrates the coming technical challenges as our use of smartphones evolves further. The increase in mobile video traffic puts a higher demand on connection speeds, as does the number of devices supported in some rural areas. Rebecka’s life has no boundaries between the virtual and physical worlds. Rather, her digital activity reinforces her daily life, often through gamification. This always-connected, always-communicating, always-mobile behavior puts network resources and network reliability front and center.

This level of activity is highly dependent on improved connectivity that enables new kinds of services.
A distributed life

Sven puts on his hard hat before leaving the local control room, heading for the elevator that will take him seventeen floors down the mine. The sudden chill in the hall makes him close his jacket even further. He is one of only a few service technicians placed at the mine, historically a working place for thousands. Nowadays most of the trucks and drilling equipment are operated from Stockholm, more than 1200 km away.

Before leaving the room he checks that all of the necessary datastreams, such as sensor messages, high resolution video from down the mine and some blueprints, are reflected on to his handheld screen. This gives him all the right tools when he reaches the faulting excavator 540 meters underground. As a precaution he activates his own live video stream, from the small camera in the hard hat. This live video is viewable from anywhere in the world, as well as the information on his screen.

“Anything serious?” Melissa asks holding up the door to the elevator. They start the descent together. Both have worked in the mine for years and they have become close friends.

“No, not really. Probably just a malfunctioning sensor. So, how did you like last night’s performance?”

Yesterday evening they both attended the local theatre. A unique concert where some of the world’s most famous opera singers performed was shown. Only two of the singers were physically present though, the others joined in on link both from the Teatro dell'Opera in Rome and The Royal Swedish Opera in Stockholm. Thanks to stable networks connecting the singers, audiences attended the show in all three places at once.

“It was magic! I am going again tonight.”

Stepping out of the elevator together, Sven checks his screen for guidance. Suddenly a small electric service vehicle appears to take them further down the tunnels. Rattling along, they keep chatting about how starstruck they feel from last night’s performance.

Challenges: Extreme reliability and computation distribution – and the end user perspective

Already today we see how mining equipment as well as forest harvesters are run from a distance. With more reliable sensors, more and more machinery will be remote controlled over mobile networks. Fleets of drones, different self driving vehicles and robots will put real time communication to the test. As well as the distance between the operator and the machine.

This development is increasing the demands on networks with extreme reliability, as well as distribution of computation. Not only will connected machines need to make their own decisions, they will also need the help of other connected “things” around them, as well as more heavy computational resources in the cloud.
Annie, yoga instructor at 82

Annie, 82 years, is getting ready for her yoga class. Every Tuesday she rolls out her yoga mat in front of a large screen on the living room wall. When she steps onto the mat it connects her to a virtual classroom and three of her closest friends appear waving on the screen.

“Hi Annie, good to see you.”

Not only is it convenient for all three to do their exercise at home. Doing it together gives them the possibility to keep in touch without the hassle of travelling.

Annie’s morning started off as usual with the sound of a gentle clatter in the kitchen and the smell of fresh coffee. And then the smiling face of Marco peering in through the kitchen door.

“Are you awake, Annie?”

An hour earlier he was identified and admitted by the electronic lock on the front door. Now he steps into the room to help her get ready for the day.

During the night her sensor-filled bracelet has registered her sleep, heartbeat and temperature. Now the data is passed to her online medical record. Compiled for the next video check up from her doctor. Twice during her sleep, the night staff have done virtual visits, using the connected camera over her bed.

Marcos own day is filled with similar visits, already planned on his smartphone. There is no need to check in with his supervisors at the office. Instead his time can be spent chatting with those he cares for.

While Annie eats her breakfast Marco joins her for coffee. While chatting he notices a small bruise on her arm and makes a note of it in the medical record. This will trigger a visit from a nurse later on.

Suddenly Marco gets an alarm call on his phone. Its from Elisabeth who has pressed the help button in her kitchen. He calls her up immediately only to find out that she already talked to her son. He got the same alarm and could calm his mother down. Elisabeth had trouble again trying to put on the stove. When Marco is leaving the living room screen lights up. This time with a personal message from Annie’s grand children travelling abroad.

Pictures of smiling faces on a sunny beach fill the room as Marco says goodbye, and Annie starts to roll her yoga mat out on the floor.

Challenges: Integrating the Internet of Things with complex systems and different processes, while building new business models

Seniors’ homes, like Aunt Anny’s, are probably where the Internet of Things (IoT) will be most useful in the future. Connected technologies, sensors and cameras can be used in ways that reinforce the quality of home and health care. With more effective planning, home care staff will have more time to socialize with their patients. And with closer monitoring of Anny’s health, she can cut down on today’s frequent visits to the health center. She will receive all the care she needs at the right time and in the comfort of her own home.

This future also highlights the demand of new business models where different actors need to communicate, cooperate and share information. Home care and healthcare systems also need to be integrated with systems in homes. Besides Anny and her relatives, hospitals, authorities and the mobile work force will benefit from this integration into “one system”.

Pictures of smiling faces on a sunny beach fill the room as Marco says goodbye, and Annie starts to roll her yoga mat out on the floor.
2. Scenarios

2.1 Major trends and key characteristics of scenarios

Mobility Foresight Scenarios as follow up to Wireless Foresight

The mobility foresight project is the 2010 follow-up on earlier scenario process works carried out in 1998 and 2001. The aim is to create a platform for discussion and a setting for the subsequent strategy work intended for the Wireless@KTH research department, and for the wider KTH research community. The key question formulated early in the project – “Which research areas should be prioritized to ensure Wireless@KTH continues to be a successful player in education and research within the mobile area?” – served as a reference point throughout the project work, and also aided in delimiting the work. But despite this, there is general knowledge to be gained from the scenarios, knowledge that can be inspiring and relevant to other actors inside and outside academia.

In the scenario development, focus has been put on trends and factors specifically influencing existing and future wireless systems and services, including technology/networks as well as service/business model factors. Business aspects have been included in all scenarios. One result of the work is that scenarios and factors to a large extent depend on WHO is doing what. The basic methodology for scenario creation has been applied in all projects:

- Identifying trends and factors with low uncertainty
  The trends represent wide-accepted “givens” in the discussion
- Identify important trends and factor in uncertainty
  These trends are candidates to span the “scenario space”
- Create scenario descriptions corresponding to the “end-points” in the scenario space

For the Mobility Foresight (MF) study, four scenarios were created based on two dividing issues concerning market landscape and technology development ideals. The first was whether new technology will be developed primarily with a human centric design, (the key driver of mobile technology until today); or if the new growth in machine to machine based communication will lead to a new machine centric design paradigm? The other dividing factor concerned the global market structure: will it be fragmented and chaotic, (high complexity), with new regulatory and technology opportunities, or will it be more or less similar to today’s, with a few dominant oligopoly actors, (low complexity), all over the globe? These two dimensions create a four-squared table with four different scenarios:

- **The Flash Mob** – combines a highly complex market structure with a human centric design ideal.
- **The Harmonious Empire** - combines a low complexity market structure with a human centric design ideal.
- **The Techno-clan** - combines a high complexity market structure with a machine centric design.
- **The Red Queen’s army** - combines a low complexity market structure with a machine centric design.
The four scenarios outline potential future events and developments, and the different development paths that will eventually take us there. In combination they point to a number of important trends that should be monitored closely in the coming years. It seems as if the high complexity market structure yields more innovation and development, while the low complexity market structure promotes a more controlled development with much more attention given to productivity and economic efficiency. The shift from human centric design to machine centric design could also mean that a number of today’s important actors in the market may lose ground to newcomers more adapted to the different requirements required by machine communication.

**Techno-economic scenarios**

The MF study takes a rather broad approach, addressing not only technical and economic factors, but also political and socioeconomic factors. In order to map the results on to concrete research items for the Center, it has been necessary to narrow the scope of the MF study and refine the techno-economic analysis.

Several studies into future technical scenarios have been performed since then. Of particular interest is the work in METIS2020³. This work corroborates the MF view that machine centric applications are of growing importance and that the requirements for these are quite different to the extent that it is doubtful that a single technical solution or technology can cater for all future needs. The techno-economic analysis contained in the METIS study is, however, not very specific. This has been the target of a refined scenario analysis performed at Wireless@KTH during the spring of 2014.
3.2 Update of factors, scenarios and challenges conducted in 2014

Working process to identify new scenarios
The project team consisted of six members representing industry, operator, regulator and university research: Joachim Sachs and Bogdan Timus from Ericsson, Per Emanuelsson from Telia, Bengt Målleryd from PTS and Pietro Lungaro and Jan Markendahl from KTH. We discussed technology/network and service/business model factors. A multitude of factors have converged into one network and one service scenario. Business aspects are included in all scenarios: one result of the work is that scenarios and factors to a large extent depend on WHO is doing what. We did not assess the scenarios from 2011 until the end of the work, i.e. we started from scratch.

We looked into trends and factors influencing existing and future wireless systems and services. The most important and likely factors with low uncertainty are used as working assumptions for all scenarios, i.e. we assume this WILL happen, see Appendix A. The most important and likely factors with high uncertainty are used to create the most likely scenarios. Depending on the outcome of the uncertain factors we will end up in different scenarios

Important factors with uncertainty and the factors used to create the scenarios

The analysis resulted in the following most important factors with uncertainty:

- Will unlicensed spectrum be important? How should it be used?
- How to provide indoor capacity (Macro MNO or shared small cell).
- Will network virtualization result in the emergence of a large number of local operators?
- Multi-purpose networks or not?
- Will MTC-connectivity be based on a license system, or will it be license-exempt?
- Will MNOs drive M2M connectivity or will other players do this?
- Business IoT services provided over special or MNO networks?
- Will IoT services be provided primarily by MNOs or others?
- MNO level of involvement in (B2B and B2B2C) IoT services.
- Will services be bundled by consumers or by aggregating actors?

We have identified the factors with the highest uncertainty. Depending on the outcome this leads to different scenarios. Two factors deal with network design and who controls the networks, and two factors deal with the provision of IoT services. We therefore arrive at four “network scenarios” and four “IoT service scenarios”.

The network factors are:

- How to provide indoor capacity? (Macro MNO or shared small cell networks).
- Business M2M services provided over special or mobile operator networks?

The IoT service factors are:

- The level of mobile operator involvement in providing IoT services.
- Use of connectivity of MNO networks OR special networks for providing IoT services.

Note that many factors could be designed as “either or”, but we see that we need to de-couple this reasoning. For example:
Other actors will offer IoT services regardless of how active operators are.
The number of local operators is decoupled from the number of MNOs.

This decoupling can be applied to the scenarios from 2011
• Both human and machine traffic will drive development.
• Few wide area network operators will exist no matter the number of service providers.
• Many findings deal with “who is doing what”, e.g. the role of different actors like traditional mobile operators, new type of operators and M2M service providers.

**Overall reasoning leading to network scenarios and related challenges**
For mobile broadband, outdoor capacity will be provided by MNO operated macro or heterogeneous networks. We have found two key areas of uncertainty for networks:

1. *How to provide indoor capacity and coverage?*
It could be from outdoors, using MNO macro networks, (most likely single operator networks), or it could be from indoors using special indoor networks, (most likely shared between operators).

2. *What kind of connectivity to use for M2M and IoT services?*
Here we see three options: i) Mobile operator networks, ii) Special (new) networks operated by new (non MNO) operators or iii) a mix of i) and ii).

For the network factors with uncertainty the analysis and reasoning was as follows:

- How to provide indoor capacity? (Macro MNO or shared small cell networks)
  One way is use outdoor macro networks, i.e. traditional MNO thinking. Another option is to use indoor Ultra Dense Networks, (UDN), (for example in the METIS project). This is mostly discussed in a single operator setting. This may work for “single-operator” buildings, i.e. one company using one operator, otherwise, multi-operator solutions are

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**Figure 3: The network factors with largest uncertainty and resulting scenarios.**

For the network factors with uncertainty the analysis and reasoning was as follows:
needed. UDN also needs to be discussed in a multi-operator setting and/or considering third parties and local operators for macro offloading.

For the indoor environment we can identify the following research challenges:
- The general question on how to provide more capacity combining technological development, use of more spectrum and densification of networks.
- How to exploit concepts for flexible use of spectrum (as an alternative to more dedicated spectrum) in an indoor setting? This includes aspects such as how to use an unlicensed spectrum? How to share spectrum? And, can local spectrum licenses be used?
- Since the current research focus is on single operator networks, more focus need to be put on multi-operator and shared solutions, and on virtual networks within physical networks.

• Will unlicensed spectrum be important? How should it be used?
Use of unlicensed spectrum with no guarantees (like TVWS) will be a vulnerable solution if it is the only resource available to an operator. If the actor is a market entrant, it will also require substantial investment. We find actors such as MVNO and fixed line operators in “a grey zone” that have many other assets in place: core network, customer care, operations. We believe that unlicensed spectrum can be useful as complement to actors with other resources, i.e. MNO with licensed spectrum or Wi-Fi operators.

We can therefore identify the following research question and challenges:
- How to combine unlicensed and licensed spectrum?
- What risks will an operator experience when using unlicensed spectrum?
- Are there cost capacity benefits compared to use of licensed dedicated spectrum?

• Will MTC-connectivity be based on licensed or license-exempt?
The same reasoning as above can be applied: unlicensed will be vulnerable if it is used as “the only” resource. Spectrum sharing is feasible if long-term agreements. On one hand we know that M2M applications are based on Wi-Fi, or on use of TV white spaces, but on the other, we know that reliability and availability are key issues for many M2M applications; the latter would imply that an unlicensed approach is less likely to be used.

A number of research questions remain however:
- For which MTC applications is it feasible to use un-licensed bands?
- How can MTC applications be more robust?

• Will MNOs drive MTC connectivity or will other players do this?
MNO networks will play an important role for many types of Over The Top (OTT) IoT services, i.e. without any major active involvement of MNOs. In other cases MNOs are involved as partners or have agreements with IoT service providers that need service guarantees. We can also see cases where some actors, for example energy companies, join forces, acquire spectrum and deploy their own MTC oriented networks.

In this area we can identify the following research questions and challenges:
- How to provide service guarantees (QoS) in terms of availability and reliability?
- How to charge for MTC traffic and how to distribute costs?
- What regulatory issues need to be solved in relation to net neutrality and QoS?
- What type of spectrum can be allocated to “new” types of operators?
To summarize, we can say that for network related scenarios key research challenges deal with aspects such as “who is doing what?”, “spectrum usage” and “sharing of resources”.

**Overall reasoning leading to the IoT service scenarios and related challenges**

Actors other than MNOs will most likely be the main providers of consumer-oriented services and apps, the services will be provided OTT using MNO networks. For M2M and IoT services, it is uncertain which actors will be involved in service provision, and what connectivity that can be used. We can thereby identify four different scenarios related to IoT services depending on the following factors:

1. MNO level of involvement in providing IoT services.
2. Use of connectivity of MNO or use of special networks for providing IoT services.

![Diagram](image)

Figure 4: The IoT Service factors with largest uncertainty and resulting scenarios.

- What is the level of MNO involvement in IoT service provision?

  IoT services will be provided both by networks of actors, (partner teams), with and without MNOs. In teams with MNOs the MNO involvement may vary, and will be determined by how much of the application specific knowledge an MNO has. Some services will be provided by large users, for example utilities, or by special M2M service providers. Challenges are:

  - To find reliable partners and partnership models.
  - To develop or find business opportunities within “extended silos”, (verticals), or by adopting “horisontalization”, offering shared solutions for services in multiple sectors.

- Will business IoT services be provided over special or MNO networks?

  MNO networks and special MTC networks will exist. When MNO networks are used, service guarantees are needed so that the service provider can control traffic, i.e. to form a virtual network. Special MTC networks will probably be joint ventures of “users”, for example energy companies, public safety?? OR it can be an independent MTC provider. Service providers also need to be able to control their own traffic in this case.
Here the questions and challenges are the same as mentioned above for the network scenarios: Which actors will provide the connectivity? What spectrum to use? Which actors will dominate service provision, How to provide service guarantees for MTC traffic?

4. Research Paradigm

The main research focus of Wireless@KTH is to solve key technical problems in systems for mobile services of tomorrow. However, the design of technical systems is influenced by several factors for which a clear understanding must be reached. Traditionally, nature itself, (i.e. physics of radio propagation, capacity limitations in networks etc.), has been the main constraint in mobile and wireless communication. This was the ruling paradigm in the early days of wireless communication that was dominated by national monopoly operators.

The operator decided what was technically and economically viable, and the user bought what was available. With increased competition in mobile services in the past few decades, and especially with the separation of networks and services, user needs and behavior have become important drivers in both network and service design. In the previous section, we argued that in the design of future systems for mobile services, not only end-user and service provider demands, but also value constellations and business logic are important factors that have to be modeled to provide adequate input for technical design (fig 5).

In table: User, customer needs and behavior

Fig 5. Design paradigm for design of wireless systems and services: a need to consider technical, user/usage and business related requirements.
5. Research (Focal) Areas

In this section we outline different research areas and what is included. We distinguish between Human oriented, (capacity driven), and Machine type of traffic and communication, (driven by availability, reliability etc.), and between research focused on services or the infrastructure used to provide services. We thus have four research areas, see figure 6. NB: the same infrastructure can be used for both Human oriented and Machine communication.

<table>
<thead>
<tr>
<th>Service related problems and research areas</th>
<th>Human type of communication</th>
<th>Machine type of communication</th>
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<tbody>
<tr>
<td>Capacity, QoS, QoE,</td>
<td>Market fragmentation</td>
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<td>interoperability, common</td>
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<td></td>
<td>platforms</td>
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<td>Infrastructure problems and research areas</td>
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<td></td>
<td>cost, scalability, energy eff.</td>
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<td>scalability, mix with human</td>
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<td>traffic</td>
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Figure 6: Four research areas for services / infrastructure and human / machine communication. Table heading: Human communication / Machine communication

Research Area: Mobile Services for Unprecedented User Experience

Although there have been major advances in mobile technologies, much of it has not had significant presence or impact in the market place due to the failure to successfully integrate them into viable services. The reasons for this include technological, business and social factors. Providing a superior user experience and open design platforms have proven to be the keys to success in mobile services. The recent massive success of the iPhone provides ample illustration. Increasing the data rate in the infrastructure is one way to improve user experience. However, deploying more infrastructure may take significant time, require substantial investment in rural areas, and may not always be energy efficient. In this proposal, we seek to provide substantial and measurable increases in the Quality of Experience, (QoE), for users on new and existing infrastructure by proposing a smarter, faster and convergent network that is based on deriving and exploiting extensive knowledge of user preferences and needs. The practical question whose answer may provide a relatively large societal and business impact is: Could a smarter, faster and convergent network result in obtaining an order of magnitude increase in QoE, while reducing cost and maximizing profits?
The use of a demonstration and test bed environment is central to these evaluations, and will be open to industrial and partner participants. Within the framework of EIT ICT-Labs a Mobile Service Test bed is planned, involving collaboration with Aalto University and other ICT-Labs partners. The test bed will focus on evaluating the scalability and user experience of mobile services, and involve live measurements on partner 3G/4G mobile broadband networks. Studies will involve:

- Deployment & management of services.
- Enhancing user experience.
- Service platforms & architectures – distribution of resources.
- Security & integrity.
- Performance & Business Aspects.
- Local & intermediate caching strategies.
- Semantic and context aware communication networks.
- Diverse user device architectures that allow system evaluation based on new models of device storage capability, connectivity, and functionality.
- Mobility and roaming support across a heterogeneous wireless infrastructure.
- Multi-modal user terminals designed with an emphasis on broadband communication, context measurements, and heterogeneous connectivity.
- Exploitation of data mobility and availability in business processes.

**Research Area: Services for controlling the world around us**

For mobile broadband and wireless Internet access, to a large extent connectivity itself IS the service. This is well suited for large scale and standardized solutions. A large number of systems, devices and users can be managed by mobile operators. For MTC and IOT services this is usually different in most cases. A service developer and provider need to have knowledge of the application, the industry and usually also the specific companies making use of or offering the services. Telecom companies need to understand that the core customer business is handled by another actor, for example an energy or transport company or a healthcare provider etc. Wireless@KTH is currently involved in project dealing with both enterprise oriented IoT services (energy, transport), and consumer oriented IoT services (health and wellbeing). Mobile payment and NFC services are also included.

Key issues are how user requirements are transformed into services, and how services and service platforms can be used for many customers and applications. Another key aspect is to find out why services fail, despite the necessary technology being in place. Key research topics are:

- Design, deployment & management of IoT services and platforms.
- User adoption of new services, assessment of end-user values.
- Service interoperability.
- Business models and value networks.
- How M2M and IoT service can transform businesses and industries.
Research Area: Scalable multipurpose infrastructures for wireless access

Wireless access networks essentially face two types of challenges:

- **Much more and capacity** (data rate) in IP-based access for mobile personal services. Considering the rapid, exponential growth in traffic due to the convergence of fixed and mobile systems, and the proliferation of cloud-based services, the challenge “1000 times more capacity at today’s cost level” has been laid down. The technical solution to this problem is in engineering and managing wireless access in highly heterogeneous environments. Wide-area moderate data rate systems, (4G and evolutions, <10Mb/s), primarily designed for outdoor, mobile use will coexist with very high data rate systems for portable/low-mobility use, (for example LTE, WLANs, >100 Mb/s), with very large numbers of access points.

- **Many more devices** – machine type communication, IoT, with perhaps around 50 billion devices communicating. Most of these devices cost less than a few dollars and communication, energy and deployments cost have to be at a similar or lower level.

- **Extreme reliability and low latency**: – this includes both mission critical machine type communication, as well as “the internet of senses” where humans are in some kind of control loop, for example guiding vehicles, remote surgery etc., where both extreme reliability and millisecond level delays or less are required.

Fig 7. Wireless infrastructure resource triangle.

It remains difficult to see whether all these challenges can be met by a single system, or if this requires heterogeneous solutions that also on the network level. Whereas the main research focus in the traditional generations of systems has been the air interface, (spectral efficiency and overcoming adverse mobile propagation conditions), challenges in the near future are likely to relate to service platforms, network architecture, computational resources, scalability, (both in terms of capacity and the number of devices), as well as energy and cost issues.
Spectrum and energy issues will play significant roles and new tradeoffs between energy, spectrum, data rates and cost, and they will have to be investigated. Reliability and latency have also to be traded off against system capacity. Managing resources, providing service platforms, computational, storage and connectivity services, and operating systems in large-scale and dynamic wireless environments, are important engineering and business challenges. The objective is to achieve scalable solutions and to reduce cost by using decentralized, autonomic and self-configuring techniques. Specific problems to be addressed include:

- **Rapid, low cost** incremental (ultra-dense) **deployment** of infrastructure.
- Dynamic and flexible **spectrum management** techniques.
- Automated (re-)configuration of networking and computational resources, in response to changes in infrastructure and demand; **resilience against failures or attacks**.
- Architectural designs for **low-energy** wireless access exploiting “novel” tradeoffs between spectrum, service quality and energy.
- RRM for **cooperative and competitive heterogeneous environments** including advertising and discovery of service and access offers for competitive markets.
- Infrastructure and novel networking paradigms for **delay-tolerant services**, (for example “information based” as opposed to “connection based” networking).
- Infrastructure and novel networking paradigms for **delay-sensitive services**.
- Policy-driven management that implements business-level objectives.
6. Research plan 2015-2017

6.1 Summary of challenges related to Wireless@KTH activities

Problems related to “How to provide indoor capacity” are discussed in the ongoing METIS project, with focus on more capacity and more spectrum related to Ultra Dense Networks. The focus is mainly on single MNO macro networks. Multi-operator solutions, network sharing and visualization need more attention. Some of these issues are part of the H2020 application for a network sharing and virtualization project with Huawei, Alcatel-Lucent, TNO.

Flexible use of spectrum is a key issue in the ongoing METIS and in a possible (likely) METIS2 project and/or the H2020 Pulsar project (application). These projects will cover problems related to “Will unlicensed spectrum be important and how to use it?”, and “Will MTC-connectivity be based on licensed or license-exempt?”.

We also believe that the question “Will MNOs drive M2M connectivity or will other players do this?” will need more attention. Work is ongoing on the “LTE4smartgrids” EIT ICT labs project, and the topic will also be included in an H2020 network sharing project.

Considering the challenges for the network and IoT scenarios we can observe two things:
1. They are quite “network oriented” and focus on how to deliver the service, i.e. they do not deal with the services themselves, user aspects or service platforms.
2. They IoT focus is on business, (B2B), services and not on the consumer market.

The MTC and IoT research should therefore be broadened to also include user behavior and needs, service design and service platforms. This is well in line with the observation that future ICT “infrastructure” will most likely include not only communication capabilities but also storage and processing, i.e. cloud approaches.

The second observation leads to the conclusion that more focus should be put on consumer oriented IoT aspects. Some efforts have been made during 2014, but Wireless@KTH should look more into the area and decide on a strategy. Such a strategy would be beneficial when deciding where to focus for the upcoming Vinnova and H2020 calls in the IoT area.

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4 A summary of research projects and initiatives, both in the technical and services related domains:

- Wireless@KTH approved a seed project in 2014 on wearables and MTC for sport and wellbeing, partners include SMEs Wememove and BioSync, Friskiss & Svettis and KTH.

- Vinnova has approved a pre-study on “Konsument-Orienterade Sakernas Internet Produkter: utmaningar och möjligheter”. Partners are MobiLife Center, KTH, Ericsson, IKEA and several SMEs.

- At the time of writing, (December 2014) Sony Mobile, Ericsson and KTH are proposing a wireless@KTH project on “MTC for IoT and Wearable devices 2020”.

- For the fall 2014 Seed Project call, two project proposals target consumer oriented IoT.
6.2 High-level plans for the research areas

Based on the updated scenarios with implications in the form of research challenges in combination with research topics in the four focal areas, the following high level actions to be taken:

- **Infrastructure for human (capacity driven) communication**
  Research on capacity-cost-energy-spectrum aspects are well established at Wireless@KTH. A good overall understanding and framework are understood and used, see the Wireless infrastructure resource triangle in Figure 7. Furthermore, the links to telecom regulation and polices, and to business aspects, are identified and addressed in ongoing research.

  For the coming years the following areas should be strengthened and/or developed:
  - Flexible use spectrum including spectrum sharing and combining licensed and non-licensed spectrum, previously use of unlicensed spectrum, secondary access and cognitive radio solutions have been seen as an alternative to use of licensed spectrum.
  - Inclusion of relevant data processing, storage and service platform issues also in the “wireless infrastructure”, i.e. not only communication infrastructure.

- **Mobile services for human communication**
  In this area a number of different topics are currently being researched at Wireless@KTH, see section 3. We feel that it would be worthwhile to identify and use an overall picture and framework, like the one used capacity driven communication networks. Different sub topics could thereby be linked, gaps identified and links to infrastructure and IoT services better understood.

- **Infrastructure for machine communication (driven by availability & reliability)**
  In this area activities include a large number of topics such as how to handle a large number of devices, traffic mix, cost and scalability, long-range communication, system architecture and migration strategies. The scope of research is considered sufficiently broad, but the depth of the research needs to be strengthened for all these aspects. Two topics in this area that need to be developed:
  - How to integrate local and wide area networks for machine communication.
  - Design of service platforms when integrated with communication infrastructures.

- **M2M and IOT services**
  In this area activities include a number of projects dealing with several sectors such as energy, transport, automotive, logistics, healthcare, home care and sports. The scope of the research is broad in areas such as application, but a deeper understanding is needed in the following areas:
  - Interoperability and use of common service platforms.
  - Understanding of obstacles and drivers of IoT services.
  - How IoT can transform different businesses and sectors, what do they have in common?

In addition, more focus should be put into consumer oriented IoT services.
Appendix A: Important factors and trends with low uncertainty

Here we list and comment on the factors with low uncertainty, i.e. factors that are important and where the trends and development are relatively “given”.

- Traffic volumes are growing dominated by infotainment (video) services.
- Creating new user experiences is the key driver for infotainment services
- Most of the traffic is generated/consumed indoor.
- Network expansion is to be driven both by capacity and requirements on functionality.
- Energy efficiency will be a major engineering problem for ICT infrastructures.
- The number of communication devices is increasing rapidly (device explosion).
- M2M applications dominate the volume of wireless connections.
- The network becomes a distributed computation and storage platform.
- Software Defined Networks will be a concept used everywhere.
- The number of MNOs in each country will decrease.
- MNO level of involvement in providing consumer services will be low.
- The cloud paradigm based on transparent IP-access will be the dominant design

Comments on factors and relationships to Wireless@KTH projects

*Increasing data traffic*, here 1000x more capacity (at same cost as today) and 10-100x higher data rates are on the research agenda, (these are key aspects of the METIS project).

*Energy efficiency*, this is on the research agenda, (EIT ICT labs project 5GREEN 2013-2014, and in 2015, the EIT ICT Labs project HII).

*Traffic is primarily from indoor and local area locations*. Some forecasts project that 70-80% of voice traffic, and 80-90% of data services will be transmitted from indoor locations. Offloading and dedicated indoor special solutions are on the agenda (METIS). Spectrum usage and allocation for local area need more attention (WULF project proposal driven by KTH).

Sharing and pooling of infrastructure and spectrum needs more attention (new area).

“*Device explosion*” (M2M) leads to a number of technical research challenges: a) To handle a large number of devices, scalability, long range communication, traffic mix; and b) To develop system architecture and migration strategies, to integrate local and wide area networks. These aspects are researched in the ongoing EIT ICT Labs project M2MRise, to be continued in HII.

Use of *Software Defined Networks* is ongoing driven by cost and need to shorten time for network deployment/upgrade

*The number of MNOs and networks in* each country are few or will be “fewer”.

The number of physical networks is decreasing in many countries due to mergers and acquisition and network sharing agreements. This leads to an increased need to control own traffic/users in shared networks (new area). It also leads to reduced competition which can be a risk for market development, (this is most likely to be outside Wireless@KTH’s scope).