Key Research Issues in 4th Generation Wireless Infrastructures

Maxime Flament, Fredrik Gessler, Fredrik Lagergren, Olav Queseth, Rickard Stridh, Matthias Unbehaun, Jiang Wu and Jens Zander

1998-11-01

IR-S3-SB-9864

In proceedings of
Personal Computing & Communication Workshop

ROYAL INSTITUTE
OF TECHNOLOGY
Department of
Signals, Sensors & Systems
Signal Processing
S-100 44 STOCKHOLM

KUNGL TEKNISKA HÖGSKOLAN
Institutionen för
Signaler, Sensorer & System
Signalbehandling
100 44 STOCKHOLM

Key Research Issues in 4th Generation Wireless Infrastructures

Maxime Flament, Communication Systems, S[2], Chalmers
Fredrik Gessler, Department of Industrial Economics and Management, KTH
Fredrik Lagergren, KTH School of Industrial Management, KTH
Olav Queseth, Radio Communication Systems, S[3], KTH
Rickard Stridh, Signal Processing, S[3], KTH
Matthias Unbehaun, Radio Communication Systems, S[3], KTH
Jiang Wu, TS-Lab, Teleinformatics, KTH
Jens Zander, Radio Communication Systems, S[3], KTH
SE-100 44 Stockholm
4GW-PCC@s3.kth.se, Jens.Zander@radio.kth.se

ABSTRACT

The world of communication is now developing faster than ever. Telecommunication infrastructure deployment in contrast is a slow and costly process demanding a long-range strategic perspective in decision making. As a consequence, R&D efforts are concerned with problems on a time horizon of 10 years or more. Studying the feasibility and viability of various future infrastructure architectures and potential road-maps of their deployment is the focus for the 4[th] Generation Wireless Infrastructures project within PCC. Determining technological and other bottlenecks to find key areas for research in this area is a very important element in these studies.

The methods used for this purpose are various scenario techniques. Plausible scenarios, describing the telecommunication scene in 2010, have been designed based on a number of global trends in technology, economy and politics. The scenario trends have also been verified by using a Delphi survey among leading industrials and scientists in Sweden. Based on these trends, three vivid scenarios are built which implicitly describe the different trends that have been created, for instance, the Big Brother, the Anything Goes, and the Pocket Computing. At the end of the paper, the implications of the scenarios to the infrastructure research areas are discussed. In particular, the working assumptions and key research problems in each PCC/4GW work package are revisited and prioritized according to the scenarios. The scenarios are also proposed to provide a framework for inter-relating different research activities within PCC.

INTRODUCTION

Today's mobile communication systems are designed as logically separate networks. They are primarily designed to provide cost efficient wide area coverage for a rather limited number of users with moderate bandwidth demands (voice + low rate data). The consumer of telecommunication services of tomorrow will expect to receive the same services in a wireless fashion as he receives from a fixed network. These services require (at least instantaneously) high bandwidths. It is not expected that future users are willing to sacrifice functionality for the added value of mobility - mainly because he will hardly be using any other stationary telecommunication devices. A wireless system should therefore be transparent to the user and thus highly integrated with the fixed network. Personal wireless devices should by nature be small and consume a minimum of power. Third generation mobile systems such as UMTS and FPLMTS aim at only partially solving these problems. By mainly extending second generation technologies higher data-rates, up to 2 Mbit/s are offered but only to a limited number of users at the time and only in certain areas. In rural areas only marginally higher bandwidth will be provided.

In order to enable the use of truly new and innovative multimedia services, even higher bandwidths need to be provided at a lower cost than second and third generations systems. Studying alternative technologies and architectures for such wireless access infrastructures is the aim of this project. Key limiting factors have been identified as spectrum shortage, power consumption and infrastructure costs. Spectrum shortage is mainly due to interference from other users but also due to regulation & co-ordination with existing services. Equipment power supply technology is not expected to make substantial progress (i.e., only 1-2 orders of magnitude) in the next decade, thus power consumption has to be limited.

If all these limiting factors can be set aside, there exists no fundamental restriction on the capacity in numbers of wireless users and the user bandwidth provided. By limiting, for instance the infrastructure investments (for example, the number of wireless access points to the fixed network), spectrum efficiency will become poor and device power consumption will have to be increased due to higher transmitter power and increased signal processing burden due to adverse propagation conditions. Sheer numbers of radio systems will require efficient and reliable distributed network functions in order to avoid centralized system vulnerability and excess signaling data volume. This large number of radio ports also represents large investments, which can perhaps be reduced if the access points are highly integrated. The resulting infrastructure must be able to be evolved gradually, incrementally offering better service quality to more users.

PCC (Personal Computing and Communication) is a national research program financed by the Foundation for Strategic Research focusing on these issues [1]. The 4th generation wireless infrastructure (4GW) project is one of the five PCC projects focusing on the infrastructural aspects pointed out above. The project aims at studying key problems in the architecture and deployment of future wireless access infrastructures required to realize the PCC Vision "Personal Multimedia to all at the same cost as fixed telephony today". Since the realization of this vision requires rather large infra-structural investments, no dramatic changes to the current architecture can be expected in the next few years. The project therefore focuses on an infrastructure deployment beyond 2010. The aim of the project is to establish a set of wireless infrastructure architectures and to test these for feasibility with respect to technical, economical and social limitations, as well as studying the feasibility of infrastructure deployment. The project work will thus have its focus on the key factors that are expected to limit the evolution of future wireless communication systems. The five 4GW work packages are covering topics from the physical to the network layer:

- Air interface,
- Smart antennas,
- Infrastructure architecture,
- Resource management and operators,
- Multicast networking.

The output of the project are gradually refined proposals for an overall architecture including architecture proposals for integration with fixed backbone networks, sketches of new air interfaces (if required), resource & mobility management schemes, deployment scenarios & integration with existing infrastructure components, leading applications & user groups and business models for infrastructure operation.

In order to identify the key research questions, the project has momentarily widened its scope to set the project activities and goals against a background of converging telecommunication, data communication and distributed computing technologies. The chosen approach for this purpose has been using scenario techniques to paint a more general picture of the telecom society 2010 taking technical, economical and social aspects into account. From these descriptions we deduce some of the bottleneck problems that need to be addressed in infrastructure design and deployment research. In this paper we report from these scenario studies and describe their impact on our technical research.

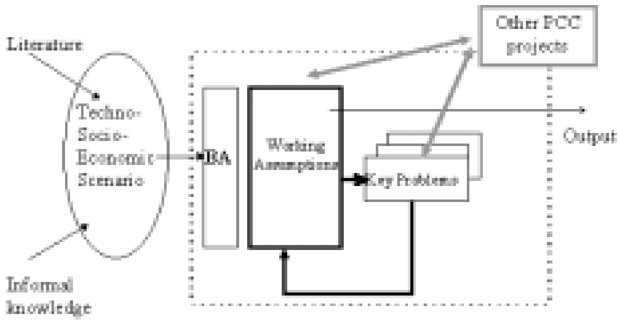

Figure 1: Process model for the 4GW project

We also outline our current working assumptions (WA:s) regarding wireless infrastructures in 2010.

CHOSEN APPROACH

The project process model is illustrated in Figure 1. The project work is focused around the working assumptions (WA) that provide the common platform for interrelating, comparing and selecting research problems in the different work packages (WP:s). The task of the WP is to derive and analyze key problems in the current set of WA. The focus is on studying the feasibility of solving these problems as well as determining performance limits set due to these bottlenecks. The result will be used to modify the WA by changing the tradeoffs between various bottleneck areas. The WA have to be consistent with a set of background assumptions (BA) describing relevant parts of a techno-socio-economical (TSE) scenario for telecommunications in the time period 2010-2020. Such scenarios address

- User behavior and lifestyle,
- Evolution of fixed telecommunications markets and systems,
- Evolving mobile terminal artifacts and their functionality and design,
- Services requirements with the focus set marketability and lead user groups,
- Projected availability of appropriate technology (hardware and reliable software).

In the long term perspective, the WA:s will also influence the TSE scenarios, as indicated by the feedback arrow. Unlike the WA, the BA's are not changed as frequently.

Scenarios have been used as a tool to initiate a research process within the 4GW group. During the last decade, scenarios have been widely spread as a managerial tool for promoting strategic thoughts within organizations. The kind of scenario methodology used was originally developed at Royal Dutch-Shell during the seventies. The methodology has since been promoted by the inventors, in [2], through the "Global Business

Network" which is a "Think Tank" and consulting firm based in California.

Brainstorming session are used to initiate new thoughts and new ideas. The result of such session is typically a list of questions and statements on ideas on wireless communications and the world in general within the next 15-20 years. Attempts to answer the questions provide more profound ideas, which create the interesting core of trends to base the scenario work on.

Creative extrapolations of these results yield chronological historical headlines, from nowadays to year 2015, stating important events in the future in agreement with one or more particular trends. Several headlines put together form embryos to scenarios. The embryos are to be developed into concrete scenarios describing different perspectives of a future.

Scenarios have two essential purposes: to change the way people think and to envision the future. First, changing the way people think is necessary to connect different factors into something of holistic character. Indeed, people are often locked in a traditional thinking pattern, which is a natural consequence of the specialization of education and functions within organizations. Second, scenarios themselves are interesting as envisions of thinkable futures; they give the possibility to test ideas and draw conclusions of many different developments.

By nature such activities are speculations although they are based on what is known today. By identifying trends and extrapolating them into the future a basis for strategic discussion can be made. Details about the methodology used can be found in [3].

SCENARIO SUMMARY

Scenarios are the outputs that reveal the essence of the world in a couple of decade. By using different perspectives, three different scenarios are built as outline below. More extensive, narrative descriptions of the scenarios are found in [4]. While the overview of the society gives us a whole picture of the world situation in 2010-2015, the user and the company perspective show a typical scene of people’s life. In next sections, the three major scenarios are briefly presented.

Anything Goes!

The development is very fast. New products and services are introduced at a very high pace. It is possible to build new local or personal networks all connected together to old networks. The networks are mostly wireless LANs that belongs to companies, residences or niche operators. Due to the high capacity and low equipment prices, the access is more or less free.

Products are easily adaptable using software technology. This makes it possible for companies to sell a product worldwide, with no hardware adaptation.

As the central control has decreased, de-facto standardization dominates combined with flexible multi-standard equipment. The competition is therefore extremely high and research is a major activity. Full exploitation yields an almost unlimited personal computing and communication world.

Big brother protects you from little brothers! – Integrity scenario

The security and integrity is put first in every step of handling information. The governments in most developed countries will cooperate to create a secure network level. This means that all citizens and companies who want to perform computing and communication have to be certified for this. For this, a new secure Internet level is created. A specialized Information Police Branch enforces the rules.

In the private sphere, information access is restricted to secure levels; most of the public information services use broadcasting because services adapted to a certain person tend to be limited. People are aware of the risks, they are careful in revealing personal data.

The impact of this scenario is that the complexity of products and services increase and thus the cost. This, in turn decreases the development rate and the number of wireless systems and operators. On the other hand, enormous amount of bandwidth is used for enhanced encryption and protection of the data.

Pocket computing or Smart devices that fits into your pocket

Pocket computing pictures the world where the technological development is fast, but due to economical and educational differences, the society is between those who can follow the development and those who cannot. Thus some parts of the population have total access, and other parts are using more simple services adapted to their needs.

The systems that existed at the turn of the century are still operational and much less expensive, while new systems have been introduced offering full mobile multimedia in certain areas and high security level. The mobile multimedia services mainly focussed on the business need. Therefore, the pricing rates are high and thus the new systems were not meant to penetrate the wide market. However, alternative package services were introduced to attract large public. The range of services available on the market is very extensive. Each service is designed for a specific need and is provided with the necessary hardware equipment. Global solutions are available but much more expensive as they rely on different services and infrastructures that are often separate entities. Thus, the pricing level is difficult to afford for private persons.

A consequence of the service situation combined with the importance of education and knowledge is that the society has been highly differentiated. Cultural and educational differences between nations have also led to political instability and unrest.

IMPLICATIONS

The scenarios point to a number of areas that are relevant for future infrastructure research. The identification of important implications is a key to the success of a group of research. These implications are found by checking each work package against the scenarios. Questions related to each working package have to be answered in each scenario case. Results challenge and, if necessary, alter working assumptions and key issues for the different work packages.

Next section describes key research issues that have been underlined in the scenarios. The second section considers each of the 4GW research topics to describe background assumptions.

Key Research Issues

In the “Anything goes” and the “Pocket computing scenarios” there are many different users of the radio spectrum, more than can possibly be handled, configured and managed. The “Anything goes” scenario implies a multitude of actor on the infrastructure market where even a user may play the role of an “operator” in his local surroundings as he installs his own low cost base stations where he needs them. This calls for techniques that automate configuration, detection of other devices, creation of ad-hoc networks and management of the radio spectrum should be allocated. Thus, spectrum regulation must be viewed in a quite different way than today.

In all scenarios, there seems to be an increased demand of bandwidth, either for carrying more services or for use by security protocols. This means that important research areas are those that makes the most efficient use of the scarce resources. Typical issues may be efficient protocols, smart dynamic resource allocation, adaptive antennas and efficient modulation techniques.

The actors in the telecom market differ in all scenarios. For example, in the “Anything goes” scenario, the user pays for communication and equipment individually and designs his own service environment using agents. On the other hand, in the “Pocket computing” scenario, the user pays for the service for which the provider supplies software and hardware needed. The impact is that infrastructure research must develop solutions that are viable in all these business environments. Ad-hod networking solutions, as in the “Anything goes” scenario require quite different business models than the more “conventional” structures implied by the “Pocket computing” scenario.

The Big brother scenario shows a centralized world controlled by government in the name of the citizen protection. Again, information integrity and security are vital areas in this scenario.

The mobility and automatic adaptation to various standards and infrastructures that provide different bandwidths at different delays opens up a wide area of research. There are questions on how to most efficiently adapt to new conditions, when to switch between systems and which layer should be responsible for different functions. This also puts requirements on applications and user interfaces that must comply to a particular quality of service even though the underlying bandwidth/delay may change.

The increased amount of communicating devices calls for more flexibility and less rigid structures. This indicates that area such as adaptive antennas and ad-hoc networks are important to study. There is a need for both new models and performance measures.

Working assumptions

The implications of the scenarios lead us to two quite different architecture types: the centralized, “operator”-driven infrastructure and the “ad-hoc” infrastructure. There are however, a lot of commonalties: The studied air interface is in the high frequency bands (30 GHz -IR). 60 GHz is a good candidate. In this kind of situation, an ‘unlimited’ bandwidth and a short range characterize the air interface. A total flexibility on the channel and service points of view is required. The terminals should be able to recognize the environment and use the channels that are available. Hand-overs should be controlled by the smart mobile devices. The MAC layer should be able to allocate adapted up- and down- links to match with the user’s bandwidth need.

The smart antennas are studied because we believe that they will play a special role together with the air interface described above, in particular in an “operator”-driven infrastructure. It is likely that several operators will want to share the same radio resources. This is possible if smart network antennas can focus their resources in one new dimension: the space. Low cost antennas will be plugged on the walls like we do with a light bulb nowadays. However, there is a major tradeoff between base station complexity versus mobile terminal complexity. Smart Antennas will contribute in some extend to the network flexibility.

Infrastructure plays an important role in the system development. On the technical point of view, flexibility is the principal problem to solve. In the ad-hoc networking architecture having multi-hop capabilities, the flexibility problem might be so big that basic assumptions will have to be dramatically changed. Tradeoffs will have to be made. The concept of cellular network has to be rethought. On the economical point of view, deployment of new infrastructure will be so expensive that it will be necessary to reuse already existing systems. Proposed solutions should be economically feasible with a gradual deployment aspect. Coexistence/cooperation with current/old networks, e.g. GSM, UMTS, DAB/DVB etc., is crucial to provide services of reasonable quality to large customer populations while new infrastructures are being deployed.

Further, coexistence of mobile networks is an advantage if multi-mode terminals are available and, most important, affordable. We foresight that there will be many different operators in the same areas; too many to afford using planning techniques that are used nowadays. Operator coexistence and automatic planning are closely related. Operator coexistence deals with issues relating to inter-firm relationships while automatic planning issues are related to activities within an organization.

Another interesting issue is the advantage of broadcast media for public and local information services. Multicasting capabilities are an alternative to the two extremes. The point-to-point communication is the major pattern we are using. Although there has been big hype for group communication, no notable applications have been found yet. The packet switching is perfect for Internet traffic, while most existing wireless wide area networks (WAN) are using circuit switching that is mainly designed for supporting real-time traffic. The importance of packet switching in the future becomes more and more obvious

The network evolution remains a key question. In the operator-driven architecture, the vast investments required, combined with uncertainty regarding technology evolution, slow down the evolution. In the "ad-hoc" architectures, standardization and efficient marketing are crucial factors to get an infrastructure to "take off" and provide sufficient coverage & capacity.

CONCLUSIONS & FUTURE WORK

The whole process to find key issues in the 4th generation wireless infrastructure has been presented. The objective and the motivation has put pressure on the 4GW group to begin such process. Using a scenario based approach, the work resulted in three major scenarios describing possible "telecom futures". Key technical & economical research issues were derived and the project working assumptions. Working assumptions and work packages plans have been updated according to the implications described in this paper.

Potential futures have been briefly presented and a mix of them should be the most likely. Strong interfaces between the WP have been developed. Both technical information flow and research responsibilities bind each of the members to the 4GW group. The scenario work gives more confidence that the 4GW group works on the right problems. The group has increased its sensitivity to trend indicators and understanding better the relevance of the individual research problems. It is our hope that the scenarios will gain acceptance or create discussion within PCC to serve as a common platform for discussion of future systems and architectures.

REFERENCES

[1] Molin, B-A, "Personal Computing and Communication -- A Swedish Strategic Research Program", *Proc PIMRC 98*, Boston, MA, Sept 1998.

[2] Schwartz, P., The Art of the Long View, Doubleday, New York, 1991.

[3] F. Lagergren, J. Zander, M. Flament, F. Gessler, O. Queseth, R. Stridh, M. Unbehaun, J. Wu, "Scenarios – a tool for starting a research process", PCC Workshop 98, Stockholm, November 1998

[4] M. Flament, F. Gessler, F. Lagergren, O.Queseth, R. Stridh, M. Unbehaun, J. Wu, J. Zander, "Telecom scenarios for the 4th Generation Wireless Infrastructures", PCC Workshop 98, Stockholm, November 1998