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Overall design of 4th generation wireless infrastructures (4GW) – A project overview & some lessons learned

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1 Introduction

A "hot" item, frequently debated in the wireless community these days is if there is such a thing as a "fourth generation" of wireless systems that is likely to appear after the successful deployment of the current third generation systems, say five to ten years from now. This supposedly "new" generation of wireless systems is intended to complement or replace third generation systems, as well as second generation systems that have already been in use for about a decade. A "classical" approach would design such a "system" in the same ways as the previous generations wireless systems, i.e. again focus on higher data rates (now beyond 2 Mbit/s) and finding new frequency bands for a world-wide standard (e.g. (2)). It is however not obvious that the roadmap is this straight-forward for a number of reasons discussed in this paper. An important factor contributing to this uncertainty is that we have very limited knowledge about the future environment in which a fourth generation wireless infrastructure should function. Which of today's systems will still exist when a potential 4G infrastructure is deployed? Which systems and solutions will be considered successful then? What technical bottlenecks will be apparent ten years from now? What market impact will third generation wireless systems have? How will this affect user behavior, and user demands? How much money do prospective users have available to pay for services provided over this infrastructure?

This paper presents some of the conclusion of of the Fourth Generation Wireless Infrastructure project (4GW) of the Personal Computing and Communications program (PCC), the major Swedish academic research effort on future communications systems launched in late 1997(1). The vision of the PCC project has been "Personal Multimedia to everyone at today's prices for fixed telephony". In 4GW a scenario-based approach has been used to tackle the issue of identifying reasonable research topics. In the paper we will present this method, and demonstrate how it interfaces with traditional research methods in the fields that the 4GW project incorporates. We will also give an overview of some research results from the project. Finally, we will conclude these results as a vision of what fourth generation wireless infrastructures might become.

2 The 4GW work process

Perhaps the most difficult issue in any scientific research endeavor is to identify reasonable assumptions for user behavior and telecommuncation systems in, say 10 years from now, such that relevant research topics may be identified. In fact, this is so difficult that most studies don't even try to do it. The approach chosen in the 4GW project was to work with scenarios. Scenarios are a tool to explore possible, plausible futures, by identifying key technical and social developments that are needed for them to be realized. The point of scenarios is not to predict the future, but to create an awareness of what future developments are possible. The research model used in the 4GW project is outlined in figure 1. As the figure demonstrates, the process began by the creation of techno-socio-economic scenarios based on literature studies and more informal sources of knowledge. The studied literature consisted of scenario methodology, as well as scenario work done by others, e.g. Ericsson(7), Siemens(8). The informal, experience based knowledge was gathered through Delphi interviews with academics and industry professionals. The resulting scenarios were used as an important input for the formulation of the basic assumptions that are an expression of the expectations and visions of the entire PCC program. From the basic assumptions, a number of working assumptions have been drawn. They in turn represent the more operational goals of the research program, and have been used to formulate the actual research problems of the 4GW project. By working in a multiple stage process, it has been possible to translate "fuzzy" societal developments into consequences for technologically defined research problems.

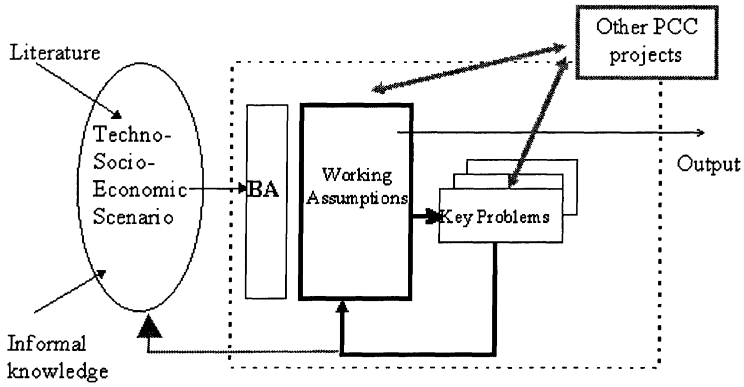

Fig 1. The 4GW work process

3 The scenarios ...

In the scenario work, three scenarios were formulated: "Pocket Computing", "Big Brother", and "Anything Goes". They address such things as user behavior and life style, telecommunications market evolution, development of supporting technologies, and evolution of values and society. The scenarios are outputs that portray the essence of what the world might become. The three scenarios are outlined below. More extensive, narrative descriptions of the scenarios can found in a full report (6) published by the project group in 1998.

Anything Goes!
The diversity of telecommunications equipment has increased dramatically, as well as the possibilities of manufacturing cheap, co-existing products. Manufacturing companies have become dominant in the telecom world. They advocate open de-facto standards, and use software solutions to create flexible, multi-standard equipment. Because of dramatic price reductions, both residential and business environments have wireless LAN solutions. They are operated by a multitude of operators, and the end-users have great freedom of choice in selecting where to purchase wireless services.

Big brother
As more and more personal information is available in the information infrastructure, personal integrity has become a major concern for the ordinary user. There is a widespread call for regulation and government intervention to ensure information integrity and secure networks. In the private sphere, most public information services use broadcasting. The complexity of products and services has increased, and thus also the cost. Service, transport and equipment providers have been reduced to a few large actors (brands) that, in the public eye, can be trusted.

Pocket computing

Technological development continues at a high pace throughout the world, but due to financial and educational differences, society is divided between those who can follow the development and those who cannot. Parts of the population have access to a multitude of advanced services, whereas others use simple services adapted to their needs. The mobile multimedia services mainly focus high-end consumer and business needs. A few operators and some very large manufacturers use standards to maintain their strategic position, and dominate the telecommunications scene.

4 ..and their implications

From the scenarios, it was possible to identify a set of key developments in the information and communication fields. They could then be expressed in terms of the following working assumptions.

Tele-presence
... is an application that will be used to create virtual meetings between individuals, and provides full stimulation of all senses required to provide the illusion of actually being somewhere else. With efficient data compression and fast sensory feedback, the bandwidth required for tele-presence is less than 100 Mbits/s. The data stream is dominated by 180-degree stereo, hi-resolution, full motion video. This type of application is likely to be the technically most demanding encounter in personal communication systems.

Information anywhere, anytime...
...with virtually seamless connection to a wide range of information services is a key feature of the future information infrastructure. Information access to large

volumes of data, pictures, video, etc., will be nearly instantaneous in small portable terminals. Compared to real-time meeting process, this application is less delay sensitive. The traffic pattern will be highly asymmetric, with 50 to 1 ratios or more favoring the system-to-terminal links.

Inter-machine communication...
...will be an important application/service. It will range from simple maintenance routines (e.g. refrigerator telling repair shop that it's broken) to sophisticated massive data exchange (e.g. camera and PC/TV exchanging video/picture information). All cars will have wireless interface as standard feature, as will household and office equipment costing as little as USD 20.

Security will be an indispensable feature...
...of the future infrastructure. Data integrity and protection against unauthorized access will be key features for providing reliable services for banking, electronic payment and handling of personal information. Schemes that reliably prevent unauthorized tracking of users and other intrusions in the private sphere will be in operation.

One-stop-shopping...
...services will be provided in a "turn-key" fashion directly to the consumer at the point of sales. The store (information provider) will take full responsibility for the service, as well as for any hardware or software that is provided.

Non-homogeneous infrastructure...
...consisting of several switching fabrics and a multitude of physical media will be the rule. All elements of significance will be digital. The fixed backbone structure will be dominated by connection-less packet switching (IP-style). The new air interfaces in wireless systems will also use packet switching technology. The wireless infrastructure will consist of a multitude of air interfaces, inherited from the wireless systems of the late 1990s, and early years of the new millennium.

Public and private access mixed.
Public Wireless access quality and bandwidth will vary. Higher data rates will be confined to dense urban areas, office environments (private/public systems) and homes (private systems). Operators and service providers will provide partial coverage for non-real-time wideband information access in most public places (info-stations).

Ad-hoc, unlicensed operation will dominate...
...and many different actors will provide parts of the infrastructure. Ad-hoc networking (spontaneous deployment, self-planning) in unlicensed bands (the 5 and 60 GHz bands) will play an important role, and compete fiercely with existing public operators, who experience dwindling market shares. Techniques for efficient multi-operator (private/public) sharing of unlicensed spectrum have been developed. Ad-hoc structures, where the equipment of the users (companies or even individuals) provide part of the infrastructure, will be adaptive to possible new communication patterns. Control of the new emerging ad-hoc networks (incl. routing, mobility etc.) will be fully distributed and highly reliable.

Multimode access ports in public systems...
...with multiple access air interfaces will be used to accommodate a wide range of terminals. Large operator systems will use advanced access ports with adaptive antennas that self-configure with non-critical installation procedures (self-configuration) to reduce cost. Access ports (wireless gateways) in ad-hoc access systems will on the other hand be simple single mode (single air interface) devices. The cost of access port hardware in these systems will be negligible in comparison with the cost of planning and physical installation.

Terminals....
...will exhibit a large range of bandwidths, from less than 10 kbits/s (simple appliances) to 100 Mbits/s (tele-presence terminals). The battery life of personal terminals will be at least one week. Battery capacity/weight/volume ratios will increase by an order of magnitude compared to today. Terminals in the 5 and 60 GHz range will use advanced adaptive antennas. Terminals will either be multi-mode, multi-function terminals, or single-purpose, cheap terminals designed solely for a specific service or function (e.g. receive only).

5 Key research areas – the WP:s

Returning to the process model in fig. 1, a number of research problems, relevant to wireless infrastructures, have been derived based on the working assumptions above. A key recurrent problem is, paraphrasing the PCC vision, to provide high data rates, everywhere *affordable* to general public. The 4GW project has conducted a number of feasibility studies focusing on techniques and architectures, given that they could be used to their full potential, could significantly change the cost or performance of wireless system. The aim is to find ways that could break the cost barrier discussed above. The project has participants from various information and communication technology research fields. Below follows brief account of these subprojects of 4GW. Details of the subprojects and their results are reported elsewhere in these proceedings.

Broadband OFDM air interface design for 60 GHz
An OFDM based modulation is a good candidate for broadband wireless systems. This scheme is well suited for transmitting high data rates in frequency-selective slow fading channels, and in the case of a properly dimensioned system the fading experienced by each sub-channel is flat. In several countries, the 60 GHz

unlicensed band provides up to 5 GHz of available bandwidth. New FCC recommendations allow us to plan for even more spectrum. In this band, we showed that coverage is not the main limitation in indoor office deployments, but rather that the short burst interference and the body shadowing create critical problems. Using a ray tracing simulator, we have studied the dynamics of the 60 GHz time varying channel in particular situations typical for office or shopping mall environments. Significant limitations, such as shadowing and fast variation of the interference characteristics in office and shopping mall environment, have been investigated. The results give a clear idea of the time variations of the channel quality for which we try to identify potential solutions. For this kind of channels, an orthogonal frequency division multiplexing (OFDM) based modulation is a good candidate. This scheme is well suited for transmitting high data rates in frequency-selective slow fading channels, and in the case of a properly dimensioned system the fading experienced by each subchannel is flat. Recently, we investigated promising system design for OFDM air interfaces. One example is based on distributed access point (AP) networks, called Virtual Cellular Networks (VCN), combined with multiple receiving antenna terminals.

Smart Antennas for 5 GHz
Using the 60 GHz band requires an increased number of access points, but may allow inexpensive radio access equipment. Systems at 5 GHz offer greater range, and have the advantage that several users can share one access point, which offers flexibility for the operator at the cost of more complex access points. Smart Antennas, i.e. antenna arrays in combination with advanced signal processing, is a tool for improving the capacity of such systems.

Our research results so far show that dual arrays at above 5 GHz, in indoor environments, fulfil the 4GW requirements of link capacity. The results indicate that operation at 5 GHz is an important alternative in the 4th generation wireless systems in all the presented scenarios. In addition to further work in this area, e.g. to map the network properties, an infrastructure study is needed in order to compare coverage and QoS vs. infrastructure cost for the proposed systems.

Wireless infrastructure architecture
The scenario work revealed three key attributes of future wireless infrastructures: very high data rates (up to 100 Mbps), simplicity and convenience in using devices and services (one-stop shopping), and flexibility (ad-hoc installation, unlicensed operation).

Our results show that user-deployment is indeed a viable alternative to traditional infrastructure installation methods. In particular, dense networks, which are typically required to satisfy the high capacity demands in for example office environments, are tolerant to arbitrary placement of the access points, as long as they are reasonably uniformly distributed over the entire area. However, our studies show that 60 GHz systems are slightly more sensitive than 17 GHz systems due to more difficult propagation characteristics. In densely populated, large buildings such as shopping malls, train stations or airports, user-deployment also achieves acceptable performance, although access point placement will require some coarse preplanning. This effort can however be limited to visual inspection of the site in compliance with a set of basic guidelines, and no expert knowledge in cellular planning is required.

Wireless resource management in multiple operator infrastructures
As noted in the "Anything Goes" and "Pocket Computing" scenarios, some feasible evolution paths will entail a large number of different services, offered over various types of access infrastructures. The number of operators and service providers will increase, as will the capacity requirements of the services they offer. In order to make future wireless services reasonably priced, we need to find more efficient methods to share frequency spectrum. Traditional licensing techniques, widely used today, are inadequate.

The aim of this subproject is to determine the feasibility of unlicensed operation for spectrum sharing. Our research results clearly demonstrate that efficient infrastructure deployments are possible in environments where multiple operators share unlicensed frequency spectrum. Unlicensed infrastructure deployments can be made as efficiently as traditional deployment, based on licensed operation. The technical feasibility of such evolutions has thus been justified. Different techniques for frequency sharing have been studied in relation to infrastructure deployment, and frequency hopping appears to be the preferred alternative. Isolation (i.e. attenuation) between operators' infrastructures improves the total available capacity. Techniques for increasing isolation will thus become key in an unlicensed environment. Examples of such techniques include smart antennas.

Seamless IP mobility support for mobile applications
In the "Anything Goes" and "Pocket Computing" scenarios, it was noted that a heterogeneous network infrastructure will play a crucial rule in building up a liberal communication market and providing a large number of innovative services. In these scenarios, the network infrastructure is not built in a well-planned way, so protocols need to be flexible and robust enough to survive despite the diverse nature of the infrastructure. This subproject investigates how seamless IP layer mobility can be supported in fourth generation wireless infrastructures. Studies are focused on both Mobile IP and IP multicast. Enhancements in both protocols for supporting IP layer seamless handover are needed.

With proper enhancements, the current Internet protocols are able to support IP layer mobility. Our research has shown that with our suggested protocol enhancements, IP layer handover latency for IP multicast is small enough to support real-time applications. In the case of Mobile IP, we believe it will be possible to achieve seamless handover in a near future. The research results demonstrate the feasibility of a heterogeneous network infrastructure, evolving through an integration of the current Internet and wireless networks. Using IP layer mobility support, wireless networks can be constructed very flexibly. Network operators will be able to provide mobile Internet services with ease, thus allowing innovative applications to be developed and deployed quickly.

Asymmetric wireless infrastructures

High demand for mobile Internet and interactive services will characterize the use of the future wireless systems. As a consequence, a large amount of traffic will be asymmetric, with user terminals requesting large amounts of data. Exploiting this fact in network design may have significant implications on infrastructure deployment costs since higher transmitter powers can be used in base stations.

6 Conclusions

The systematic process to find key research issues for fourth generation wireless infrastructures, based on the PCC vision paraphrased as "wireless high data rates - affordable everywhere", has been presented. Using a scenario based approach, the work resulted in three major scenarios describing possible "telecom futures". Key technical and business-related research issues were derived, and working assumptions for the project were formulated based on the scenarios. An overshadowing barrier in current system design, prohibiting the implementation of the vision by current techniques has been identified: the cost per transmitted bit remains almost constant as we increase the data rate. Some feasibility studies have been conducted in the project, studying key techniques or technologies that had the promise of breaking these cost / performance barrier.

The results of these ongoing studies show that user-deployed system remains as a viable candidate for short-to-moderate range wireless system with very high data rates (<100 Mbit/s). Further advances in array signal processing are shown to be practically applicable in these environments, with the potential to substantially reducing the number a required access points. Ad-hoc, multiuser/multioperator systems can be made working in these environments, but without careful system design, this can be incur a severe performance penalty. Current CDMA-type solutions do not work in this context. Mobilty management remains a big challenge in "low-hierarchical" network architectures as outlined in the working assumptions. Although, for the most demanding applications (multicasting/multiparty teleconferencing) significant progress has been reported.

The scenario work has also provided confidence that the group is working with the right problems. The scenarios have gained acceptance and created discussions within the PCC program, where they serve as a common platform for discussion of future systems and architectures.

8 References

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

(2) Hata, M, "Fourth generation mobile communication systems beyond IMT-2000 Communications", Proce APCC/OECC '99. Fifth Asia-Pacific Conference on Communications and Fourth Optoelectronics and Communications Conference , 1999 , Page(s): 765 -767 vol.1

(3) Pereira, J, "Fourth Generation: Now, its personal!", Proc. Personal, Indoor and Mobile Radio Communications, PIMRC 2000, Volume: 2 , 2000 , Page(s): 1009 –1016

(4) A Bria, M Flament, F Gessler, O Queseth, R Stridh, M Unbehaun, J Wu, J Zander "4th Generation wireless infrastructures - scenarios & research challenges", IEEE Personal Communications Magazine, December, 2001.

(5) M. Flament, F Gessler, F Lagergren, O Queseth, R Stridh, M Unbehaun, J Wu, J Zander "An Approach to 4th Generation Wireless Infrastructures - Scenarios and Key Issues", VTC 99, Houston, TX, May 1999

(6) M. Flament, F. Gessler, F. Lagergren, O.Queseth, R. Stridh, M. Unbehaun, J. Wu, J. Zander, "Telecom Scenarios 2010 - a wireless infrastructure perspective", http://www.s3.kth.se/radio/4GW/public/Papers/ScenarioReport.pdf

(7) Ericsson, Scenarios, 2000-12-18, Kontakten no. 1, 1997.

(8) Siemens, Scenarios, 2000-12-18,