Low Cost Broadband Wireless Access –
Key Research Problems and Business Scenarios

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Abstract–**The most prominent problem in providing any-where, anytime wideband mobile access is the towering infrastructure cost as it is basically proportional to the bandwidth provided. In this paper, we provide a simple, initial, analysis of the various infrastructure cost factors. This analysis shows that, contrary to what one may expect, the infrastructure cost is not dominated by electronic equipment, but rather by other deployment related costs (towers, wiring, building, network connections) and maintenance costs. In the paper some novel architectural approaches for future wideband mobile access focusing on these dominant cost factors are described and the related key research issues are discussed.**

I. INTRODUCTION

Today's mobile communication systems are primarily designed to provide cost effective wide-area coverage for users with moderate bandwidth demands (voice and low rate data). In contrast to the traditional mobile systems, wireless local area networks (WLAN) are designed for higher bandwidth demands, while the area coverage is significantly limited. What the consumer of mobile telecommunication services of tomorrow will expect to receive, besides some vague notion of the "Wireless Internet", is not that clear. However, to obtain a widespread demand for wireless services, they have to be widely available, simple to purchase and access, and they must be affordable to large numbers of consumers. We expect that providing higher bandwidths that enable the use of truly new and innovative multimedia services is not sufficient: the users' communication cost per month must be similar or even lower than in second and third generation cellular systems.

Providing cost effective, affordable wireless bandwidth (almost) everywhere is one of the key success factors for future wireless systems. As the success of the Internet is largely attributed to the fact that it is virtually free of (incremental) charges (such as flat rate, independency of traffic volume), it is generally perceived that mobile data communications has to provide services in a similar way.

The challenge of providing flat rate, wireless access at the cost of fixed Internet access is indeed hard. The conventional cellular concept does not scale in bandwidth in an economical sense. The cellular systems include both the radio access network (RAN) and the core network (CN) components, which have different cost and capacity performance. The more decentralised WLANs have a slightly shifted RAN/CN performance relation due to short range and high access capacity. The cost of the wireless infrastructure (C_{system}) can (for a given allocated spectrum) basically be broken down into the following factors[1]:

$$\frac{C_{system}}{N_{user}} \approx \frac{c_{AP}N_{AP}}{N_{user}} \approx c'B_{user}A_{service}f(Q) \qquad (1)$$

Where

N_{AP} the number of access points (base stations)
N_{user} the number of users
B_{user} the average data rate of the users
$A_{service}$ the service area covered (volume indoors)
$f(Q)$ is a function of the required Quality of Service.

We here assume that cost of the core network part (wiring, switching nodes, servers and gateways etc.) is proportional to the number of access points and can thus be included in the factor c_{AP}. The cost factors generally depend rather weakly on the basic radio technology (e.g. the air interface) employed. This is mainly due to the fact that current modulation and signal processing technologies are quite advanced and so close to the Shannon limits that a radical improvement in signal processing capabilities alone will not significantly improve the performance. An abundance of spectrum may to some extent

Clearly, mobile telephony users have got used to large coverage areas with relatively good coverage and service availability (anytime, anywhere). This has been feasible since the bandwidth B has been low. Maintaining $A_{service}$, N_{user} and $f(Q)$ constant, it is clear that the cost is directly proportional to the user data rate, or equivalently, the cost per transmitted bit is the same. The classical telecommunication approach is to provide strict Quality–of–Service (QoS) guarantees at very low levels in the network hierarchy, corresponding to a high $f(Q)$. Sacrificing some Quality–of Service would thus be one way to significantly lower costs, but this has to be done in a way so that we can still provide interesting and desirable end-user services. Packet access techniques without absolute delay guarantees, e.g. the new HSDPA standardization effort in 3GPP is one

example of looking into more flexible resource utilization.

Other critical issues are related to financial and business aspects of the deployment of such a wideband wireless infrastructure. In traditional telecommunication world, a monopoly operator could make large investments in infrastructure, expecting to recover these in 20, 30 years. In a rapidly changing industry, this seems no longer to be an option. Today's vertically integrated market with operators "owning" the customers, providing most of the services and also owning and operating the network. Evolving network technology now enables that all functionality for customer care & billing as well as all network infrastructure may be offered on a disintegrated market by many different companies. Other players are service providers and Mobile Virtual Network Operators (MVNO), operators entirely without their own access network. We can also expect that the network access can be provided by specialized network providers and by private persons or enterprises. Mechanisms for sharing the cost (and risk!) for the deployment of new wireless infrastructure among these players are no longer obvious. One may well envisage infrastructure solutions that, at the aggregate level over a long time horizon, have the potential to provide reasonable costs for the end-user, but where markets and the cost-sharing mechanisms are not properly working. This would, in turn, prevent an effective take-up. Clearly, solutions have to be sought in the intersection of infrastructure business models, regulation and wireless technology.

The engineering challenge is to find technical designs that reduce costs significantly. We will see that the traditional approach, to provide cheaper and cheaper equipment is not alone going to solve the problem. To explore what kind of solutions that need to be sought, we will in the following take a more detailed look into the cost structure of wireless infrastructure in order to find the dominant cost. Based on this analysis, we will propose some alternative infrastructure concepts and architectures for future wireless systems, which focus on these dominant cost factors. Of particular interest are system concepts that allow simple and cheap deployment of infrastructure and concepts that allow efficient sharing of infrastructure resources.

II. COST STRUCTURE AND COST DRIVERS IN WIRELESS INFRASTRUCTURE SYSTEMS

. Figure 2 shows an example of a cost structure for a typical cellular operator. The large grey sections, are related to marketing and administration and constitute 55% of the total cost, whereas the remainder, the colored slices are related to the network and infrastructure.

It can be noted that the annualized equipment (i.e. the depreciation cost for the equipment investment), e.g. base-station and switching equipment, is only a small part (15%) of the total infrastructure cost.
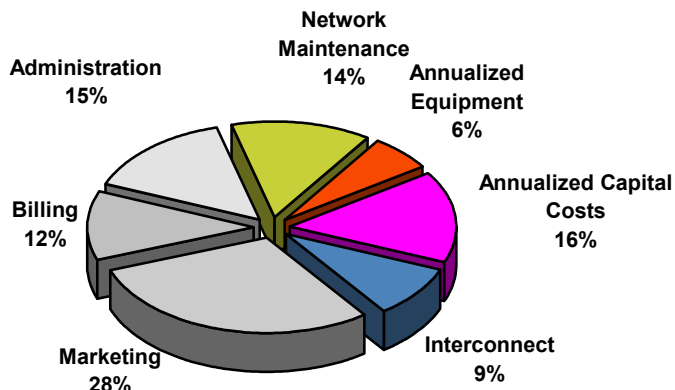

Figure 1 Cost structure for US mobile operators in the mid 90`s(FCC).

The other investment related costs are mainly due to site construction, antenna tower and similar items. The trend is that equipment related costs are becoming even smaller in future systems (with the possible exception of temporary "glitches" when new technology is introduced, before it has "gone down the learning curve"). In the rest of this paper we will mostly focus on the costs related to the network and infrastructure.

Operator costs for the network are often expressed as Capital expenditure (CAPEX) and Operating expenditure (OPEX). CAPEX are costs related to investment in equipment and the costs for the design and implementation of the network infrastructure; site acquisition, civil works, power, antenna system and transmission. The equipment includes the base stations (AP´s), the radio controllers, BSC´s and RNC´s, and all core network equipment. An example of CAPEX and of the relations between different types of implementation costs are shown in Figure 2.

In Figure 3 the relative costs from figure 2 are shown as a comparison. The same conclusion can be drawn from the both estimates; costs for base stations sites are much higher that costs for the base station equipment. We can also expect this difference to be larger over time due according to Moore´s law and the learning curve
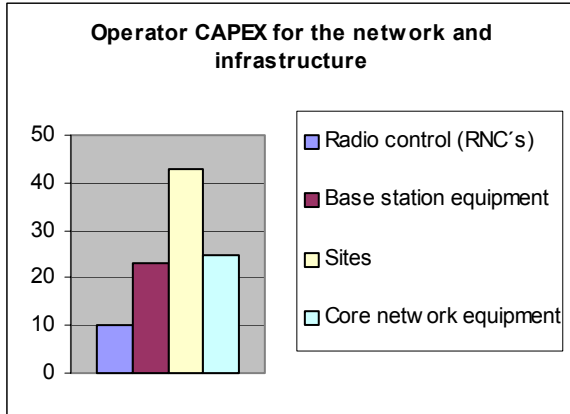
Figure 2 Example from 3G networks in Germany, estimates of cumulated CAPEX for the first 9 years [5]
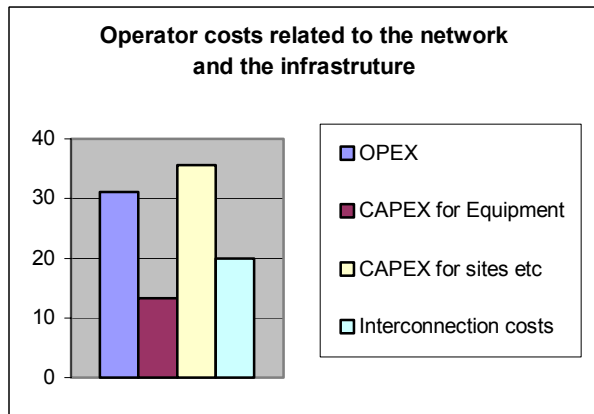
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Figure 3 Network costs from figure 2 shown as comparison to figure

The OPEX are made up of three different kinds of costs

- **Customer driven,** i.e. costs to get at customer, terminal subsidies an dealer commissions
- **Revenue driven,** i.e costs to get a subscriber to use the services & network or costs related to the traffic generated; service development, marketing staff, sales promotion, interconnection.
- **Network driven**, costs associated with the operation of the network; transmission, site rentals, operation and maintenance.

Our current knowledge indicates that the dominating factors are related to customer acquisition, marketing, customer care and interconnection.

The fraction of OPEX to the overall cost is of course changing over time; in the "mature" phases the OPEX is the dominating factor. However, an estimate indicates

that the network related OPEX are roughly 25 % of the total costs for the full life cycle.

Some general conclusions we may draw based on this simple analysis are:

A. Equipment cost is not the dominant part of the overall network CAPEX or OPEX.
B. The fraction of equipment cost to total infrastructure cost is likely to be reduced over time
C. Site construction & deployment costs and rents are the a major part of the network costs.
D. Network maintenance costs are a significant

III.   SOME POSSIBLE RESEARCH DIRECTIONS

Based on the conclusions in the previous section, we can now identify some of the potential technology components of a cost effective solution. These are illustrated in Figure 4. Combining these technologies leads to a number of distinct research directions ("road maps") as indicated in the figure.
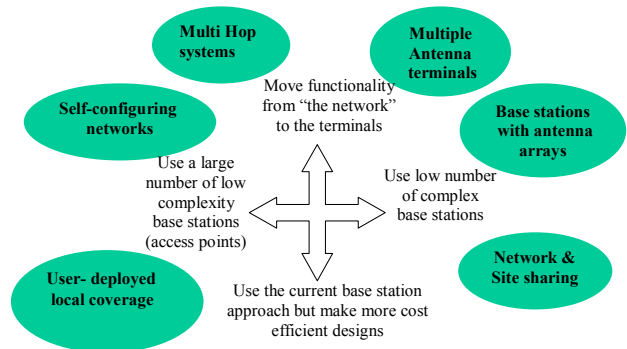

Figure 4 Possible solution components & research directions to provide low cost infrastructure .

As can be seen in the figure each of the directions correspond to approaching one over several of the cost drivers in our infrastructure cost model. Lowering the number of access-points by increasing their efficiency is a obvious approach. Using terminals to forward messages to other in a multi-hop mode, can also reduce the number of base station sites. Self-configuring technologies allows for reducing planning and deployment costs as well as O&M costs is also an interesting paths. Finally reusing and sharing infrastructure between operators and user is also reducing the number of required new sites. In the following we will present a number of candidate architectures illustrating how these technologies could be applied. Fig 5 shows how these candidates are related.
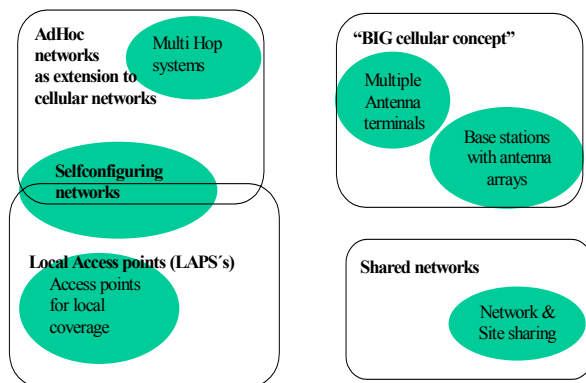
Figure 5 Proposed architectures and solutions for low cost infrastructure

IV. SOME CANDIDATE ARCHITECTURES AND KEY RESEARCH ISSUES FOR LOW COST INFRASTRUCTURES

"BIG cellular" concept: Highly efficient base stations

Since the infrastructure CAPEX is dominated by site related cost, and not by equipment, one obvious philosophy for decreasing the cost is to keep the number of base-stations low. This of course requires that the capabilities in terms of range and capacity of each base-station has to be high. Measures that can be taken increase the capability of each base-station is the use of high power, smart antenna arrays and high-gain antennas, high masts and use of low frequency bands. These measures make the base-station "big" in different aspects.

The working assumption is that a "traditional operator" owns and operates the network due to the need for large investments, centralized control and high competence to build and operate a "BIG cellular" network.

Among the key research issue for this concept we find

- Design and integration of efficient spatial RRM
- MIMO performance in hot spots, city centers
- Life cycle cost structure for the base stations
- Mobile terminal feasibility and cost
- Potential with "relayed approach", i.e MIMO technology for a more advanced transceiver acting as a relay port for a small local area network

Easily deployed Local Access Points (LAP´s)

In this strategy, we aim to bring down costs for network planning, deployment and maintenance by deployment of "many" low cost "base stations". These LAP´s should be possible to deploy "anywhere" where power and wire line connections are available and thus they require no specific "sites". Deployment & planning

and O&M should be quick, simple and automatic, thus implying built-in functionality for auto-tuning and self-diagnostics.

Some key research issues that would need to be considered for this concept

- Cost efficient design of multi radio access LAP
- Principles for RRM and frequency & channel allocation of licensed bands used by LAP´s
- Design of LAP support functionality for "self deployment", configuration and auto-tuning
- Principles for support functionality for self-diagnostics, failure reporting and re-configuration
- Cost efficient design of multi radio access terminals with additional bands for voice communication using "local wireless access"

A related key issue is if it possible to provide interesting services over what can be seen as a combination of cellular systems and an organically growing infrastructure where individual users, companies and operator contribute to provide capacity and coverage - "the internet way".

Shared infrastructure

Present cellular solutions where (traditional) operators co-operate using national roaming or operate a common shared network. National roaming will be sufficient in rural areas where coverage is the main issue, in urban areas where high capacity is to be provided shared common network is more cost efficient. To reduce the number of sites, these should be utilized with high degree of efficiency; in the case of common shared networks one solution can be multi-operator base stations with all the frequency bands licensed to the operators.

The total number of sites is reduced, resulting in benefits due to higher efficiency in the usage of network equipment, transmission and sites. Costs for the site acquisition, operation & maintenance and interconnection, will be reduced due to fewer sites. On the other hand, planning need may be increased in areas where the operators will use most of the allocated spectrum.

This is clearly an evolutionary strategy and no changes will be needed for the mobile terminals

The current sharing solutions allows reductions of CAPEX and OPEX up to 40-50% [[3][5]. We believe there exists a large potential for further savings for the operators, however today no real incentive for the vendors exits today.

Among the key research issues we find

- Efficiency in deploying and operating the shared network (how much can be gained?)
- Fair sharing of resources (RRM)

- Pooling of resources from different operators
- Design of multi-operator base station
- On line tracking and monitoring of resources as input to traffic statistics, billing and planning.
- Principles for generalized roaming where many network providers contribute to the coverage

AdHoc networks extensions to cellular networks

To extend the coverage of the present cellular systems without adding more base stations one option is to use self- organizing adhoc networks based on terminals and /or repeaters with multihop, routing and buffering capability. The total number of sites is reduced or maintained. No planning will be needed since the network is self-organizing. More functionality will be added in the terminals such as network control and routing and buffering, also the physical design itself must allow for more memory and power consumption.

The key question is whether it is at all possible to provide interesting QoS guarantees in ad-hoc systems with little or no control over system resources and where propagation conditions, user location and radio interference may be unknown or hard to predict quantities. Resource management in the wider sense would be a critical issue.

V. BUSINESS SCENARIOS

Why business scenarios?

In order to evaluate the cost–performance characteristics of the proposed candidate solutions a wide range of use cases, user needs, business models and deployment strategies have to be considered. The candidate architectures target different sets of use cases and requirements, i.e. all solutions are not applicable everywhere.

Below some scenarios are described to highlight where the main benefits of a specific solutions can be expected. The presented scenarios are neither "user centric" nor "operator centric", they can be characterized by being more "deployment centric" in order to illustrate and highlight

- the need and use of new business models
- the different sets of requirements and working assumptions needed to evaluate the candidates.

For the "proof of concept" phase in the research, the scenarios will provide a common set of system and user requirements.

The proposed candidate architectures will be mapped onto an overall "market space " with local and wide area on one axis and "type of access provider " on the other axis.

"BIG cellular" concept

The "BIG cellular" solution targets requirements and scenarios with wide area coverage and high capacity, i.e. high performance cellular systems.

The scenarios of interest include both the traditional mobile operator business model and new business models where user owned equipment may contribute to the "infrastructure" e.g. by moving gateways in cars, buses and trains.
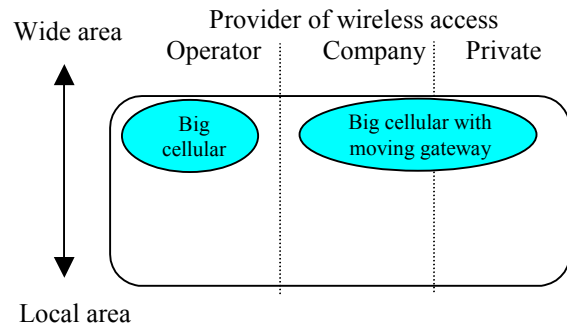

Figure 6 Big Cellular Scenario

Easily deployed Local Access Points (LAP´s)

The LAP´s are owned by the house or facility owner or by a specific local access provider. LAP´s used in domestic and corporate environments are intended for "own" users, i.e family and employees of the own company. Access for visitors can be an optional feature.

When maintenance is needed this is most likely provided by specific service companies.

For this local area (mainly indoor) candidate solution, where "other" market players than mobile operators (private persons, companies, facility owners, hotels, shopping malls) own and /or operate the wireless access infrastructure, we will consider two different business scenarios:

- Privately owned access networks mainly intended for the own users, but public access is possible. The main drivers are cost reductions and service performance for own users, i.e. not the possible revenues for the public access. An important part of the scenario is the re-use of existing fixed infrastructure and (in the case of companies) also "re-use" of staff for operation and maintenance.

- Local access providers for public use, i.e. no "own" users" exist. The main driver is to make money on the access itself and possibly to support the "core business", e.g fast food or coffee shops.
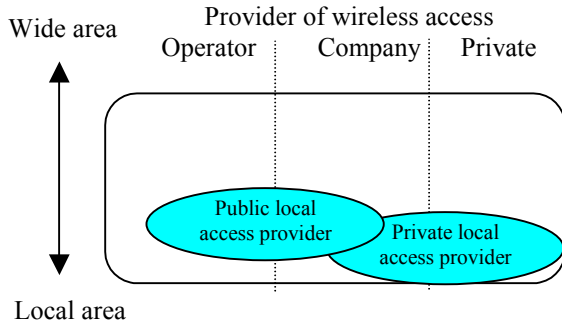

Figure 7 Local access provisioning scenario

These business scenarios may include regulatory issues as "local licenses" of spectrum and franchising solutions, e.g. to operate the network in area X "on behalf of " operator Y

For the first scenario we also have to consider the types of agreements the customer most likely will have with a phone company, a mobile operator or an ISP with a "common" subscription and terms & conditions for the usage of coverage & capacity offered by the owner of the LAP.

AdHoc networks extensions to cellular networks

One set of scenarios for adhoc networks includes fast rollout, rapid deployment and/or intermediate solutions for capacity & coverage expansion.

One driver is the possibility to provide customers with some degree of access in the near future, compared to the case where full quality access is provided when the full network rollout or expansion is finalized.
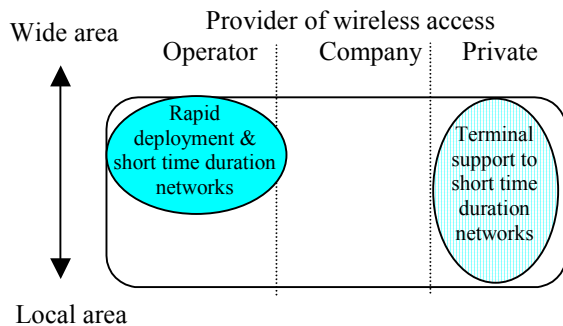

Figure 8 Ad-hoc/Rapid deployment scenario

This is believed to be important for market entrants (greenfield operators) in order to acquire customers, to

get some revenue and in order decrease the number of customers for competitors.

Other scenarios include self-organizing networks to handle hot spots with short duration (e.g. traffic jam). One driver for this kind of solution is to cut traffic peaks without any need for "over-dimensioning" of the network.

Shared networks and use of common resources

One scenario focus on co-operation between operators in order to save costs and to make more efficient use of "all" available resources in an area including strategies as co-location of sites, pooling of telecom equipment and/or frequency bands. In this scenario cost reduction for OPEX and CAPEX is the main driver.

Another scenario, which is similar to the previous one with terminals forming adhoc networks, can be identified in areas with sparse infrastructure. Here co-operation between different "competing" network providers, including the users "belonging" to different operators, may be required in order to be able to provide ANY access at all in an area. Coverage and capacity can be offered at lower "total" cost and/or more early compared with parallel full capacity and coverage networks.
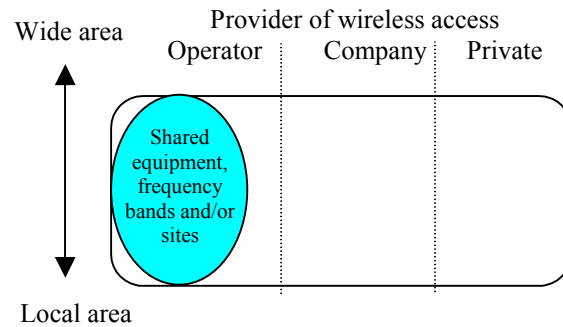

Figure 9 Shared network scenario

VI. DISCUSSION

In this paper we have identified the infrastructure cost as one of the main barriers en-route to pervasive wireless mobile access. We provided a brief analysis of the key cost factors in the wireless infrastructure and concluded that a scaled-up version of the traditional cellular concept is not by itself a viable solution to any-time anywhere broadband wireless access. Our analysis points at that the cost of equipment is like to be only a small fraction of the total infrastructure cost, whereas the bottlenecks lie mainly in the planning, deployment and maintenance of the infrastructure. Some new architectural concepts targeting these bottleneck costs were given. Most of these concepts in themselves provide non-trivial technical bottlenecks that could provide interesting new directions for engineering research. It is by no means obvious which of these

concepts (if any) is providing the most effective solution to our challenge. It is on the contrary likely that good solutions can be found in combining some of the features of the archetypical system designs outlined above.

VIII.   ACKNOWLEDGEMENT

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