PLANNING OF A BROADBAND WIRELESS NETWORK BASED IN OFDM

General Considerations

Benigno Rodríguez
Institute of Electrical Engineering, Universidad de la República, Julio Herrera y Reissig 565, Montevideo, Uruguay

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Abstract: In this paper several hints to be considered in the design of a commercial broadband wireless network are presented. The case of study is based in Worldwide Interoperability for Microwave Access (WiMAX) networks, but the general concepts are also valid for Long Term Evolution (LTE).
The information presented here is not only valid for the task of designing a broadband wireless network, but also it can be useful to focus research in the economically most sensitive areas.

1 INTRODUCTION

As an example, the design of a broadband wireless network based in OFDM for 50.000 subscribers will be analyzed.

The main concepts of New Generation Networks (NGN) will be considered. One important concept in NGN is the separation between services and access technologies. In this way the development of new services is simplified, because under this concept is not necessary to be a telecommunication expert to develop services, the activity is also open for example, to information technology experts. Also it is an interesting opportunity for universities to develop new telecommunication services, and to have an even more active participation in the development of this industry.

To enrich services also *Service Control Engines* (SCEs) [1] are integrated to networks. They provide traffic analysis in order to apply different policies to different customers.

2 NETWORK OVERVIEW

In next subsections the standard components of a WiMAX or LTE network are discussed. The analysis is focused in the most important aspects and in the new alternatives to the development of this type of networks.

2.1 Customer Premise Equipment

Exists an interesting variety of Customer Premise Equipment (CPE), simple ones, with ports for Voice over Internet (VoIP), and with VoIP and Wireless Fidelity (WiFi) ports. Also exist several devices (Notebooks, Netbooks, Handhelds, etc.) with the chipset for WiMAX access embedded.

Prices are decreasing, but they are still very significant, more than 25 % of the total Capital Expenditure (CapEx) of the network is due to CPEs (see Figure 1). Notebooks and Netbooks with WiMAX chip included, improve this fact and simplify the situation for operators.

Operators have applied different strategies in order to reduce the cost of CPEs. In the case of Yota (the Russian operator), they have decided to offer the broadband access for free during some months, for subscribers who buy their own CPEs (usually embedded in Notebooks and Netbooks)[2]. It has two desired consequences for the operator, first of all the subscriber pays for the CPE, and then the operator has not to pay for it (is not part of the CapEx). To be more precise the operator pays less for the CPE (the money corresponding to the months during which the service is offered for free). The second desired effect

[1] http://www.cisco.com/en/US/products/ps6151/index.html

[2] http://www.lightreading.com/document.asp?doc_id=184325

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is that these months for free are a very good reason for subscribers to use the WiMAX access offered by the operator, specially if the performance is better compared with the corresponding to 3G networks.

Another important consideration is that a network designed for USB dongles to be used in indoor scenarios, needs more Base Stations (BSs) than one designed for desktop CPEs. There are between 4 dB and 6 dB of difference between the gain of these devices.

2.2 Base Stations

The spatial diversity order is going to have an important impact over the number of sites (BSs) in the network. In Table 1, how the number of sites vary with the spatial diversity order[3], for a given area, is shown.

Table 1: Spatial diversity order versus number of sites.

Diversity Order	Number of Sites
2T2R	59
2T4R	30
4T8R	18

The number of sites have an important influence in CapEx and Operational Expenditure (OpEx). By using a lower spatial diversity order, a reduction in CapEx can be obtained, but later a less efficient network will have a higher OpEx. Thinking in a time frame of 10 years, generally, these cheaper BSs are not convenient (see Figure 3).

2.3 Backhaul and Backbone

A new backhaul generation with millimeter waves (MMWs) is available in the range of 57-86 GHz. The equipment is cheaper compared with microwaves, and with the advantage of a lower spectral license cost. The concept of "light licensing" is applied to MMWs.

Very directive and short range links are achievable with this technology[4]. This decreases the interference between radio links and allow a higher reuse of frequencies, both effects contribute to allow a cheap licensing.

Also Free Space Lasers (FSLs) are an alternative to consider. In some cases they are used as redundancy for MMWs links (Kamalakis et al., 2007). Using FSLs as a backup for MMWs is quite natural, and easy considering that both technologies have a similar range of distances and both are very directive. MMWs are significantly affected by heavy rains (Hansryd and Eriksson, 2009) while FSL is very sensitive to fog, then using both technologies one is backed up by the other. These technologies allow to develop high bit rates links at the same time that CapEx is reduced. By using both techniques simultaneously, the availability can be quite acceptable.

Another way of increasing the availability is by deploying rings of MMWs. Usually strong rains, that reduce significantly the performance of MMW links are concentrated in a small area and do not affect more than one link (hope) of the ring.

MMWs are considered as a good alternative for achieving the capacities needed for LTE. For sure fiber optic networks are also a good alternative for backhaul, but twice more expensive and slow to be deployed due to the installation and permissions needed.

2.4 Access Service Network Gateway

Access Service Network Gateway (ASN GW) is a central part in a WiMAX network. It is involved with mobility functions and functions which are better offered in a centralized form.

A centralized ASN GW is used to provide Macromobility (mobility in the whole network). If it is only necessary to ensure mobility in a small part of the network, an architecture of distributed ASN GWs can be used, which is a cheaper option.

In the case of LTE technology the equivalent gateway is the *Packet Data Network Gateway* (PDN GW).

2.5 NGN and Softswitch

As it was said, probably the main concept in NGN is the separation between services and transportation technologies. Other important characteristic of NGN, is that these are packet based networks, with Quality of Services (QoS) and mobility. Packet based networks brings the problematic of Voice over IP (VoIP) also called IP telephony. This approach to telephony brings several opportunities but also challenges.

In this context, the Softswitch has a very important role. Softswitch seeks to use open standards to integrate NGN networks able of providing voice, data and multimedia services. In the architecture of Softswitch based NGN four planes are distinguished: the transportation plane, control (signaling) plane, service (application) plane and management plane (Peng et al., 2003). Softswitch resides in control plane and focus on the call control capabilities. There is certain independence between planes, e.g., service plane does not care about the implementation of call control (control plane). The idea is that the interfaces between these four planes could be open and standardized in order to have a real open architecture for these networks.

[3] http://wwwen.zte.com.cn/en/products/wireless/wimax/200906/t20090619_172937.html

[4] http://www.siklu.com/

Softswitch is an excellent tool to achieve convergence, being able of working with different protocols by using generic protocols (usually five generic protocols). To achieve the coexistence between these different protocols they are translated and encapsulated to obtain a generic protocol. The benefits of these generic protocols are several, as an example, the Softswitch can be protocol unrelated, the generic model subsystem (a key subsystem in Softswitch) has to cope only with five generic protocols, which makes its task much more simple (Zhu and Liao, 2005).

Concerning to services, Sofswitch allows to increase the offer of value added services. Softswitch can also provide services by introducing specific application servers, developing in this way a very flexible and scalable service architecture based in them. Services provided by these application servers are available to all subscribers through Softswitch. To simplify and open the task of developing new services, Application Programming Interfaces (APIs) are available. Thanks to APIs, the development of telecommunication services is not only a task for telecommunication experts, also programmers -not so familiar with telecommunications- can develop new services.

2.6 Service Control Engine and Policy Server

Service Control Engines (SCEs), also called Service Inspection Gateways (SIGs), are devices able of monitoring the traffic in a network during certain time, then some statistics about the traffic in the network can be obtained, and some decisions can be taken in order to optimize the network use. Through these statistics is possible to know the behavior of the customers and then they are a good help to design new value added services. The available services in a network are going to be an important difference between Internet Service Providers (ISPs) when the customer is faced to chose one ISP.

SCEs are able of applying subscriber policies, allowing to change the class of service delivered to one specific subscriber, for example allowing to increase the velocity of the connection by some time, after asking and paying for this service through a web page. By using SCEs is also possible to apply parental control to a specific subscriber, blocking the access to certain web pages with inconvenient content. More knowledge about their subscribers and the opportunity of delivering customized services to them empowers the work of an ISP. Also quota management services are possible to deliver through the use of SCEs (services by traffic, time or modalities as “pay-as-you-go”). Also it is possible to apply specific policies to particular traffic as P2P or VoIP traffic. Spam limitation and several security improvements can be achieved by using SCEs in the ISP network.

SCEs allows a more efficient use of the network resources at the same time that allows to customize the service to the customer requirements; in this way SCEs are very useful tools in NGN. The optimum use of network resources is an important key in multiple play networks.

3 DECISIONS TO TAKE FOR PLANNING A WIMAX OR LTE NETWORK

There is a set of important decisions to make for planning this kind of Networks.

3.1 Fix or Mobile Service

It is not a question of selecting a standard, for example in WiMAX case you can use IEEE802.16e even if you are planning to develop a fix network (e.g., to start with less BSs). It is more a question of considering a business plan.

There is an important difference between the number of BSs needed for a good quality mobile service, and the number of BSs needed for a good quality fix service. It is also important to have a clear idea of what is lost in throughput to ensure a mobile service. Is also convenient to have in mind the lost performance by having the CPE 4 meters away from the window, instead of very close to it (see footnote 5).

When a mobile network is considered, omnidirectional antennas in CPEs are used, because in a mobile scenario the CPE can not be oriented in the direction of the BS. It causes a loss of approximately 6 dB. Besides this, for a mobile network a good quality handover has to be provided. These facts make that for a mobile WiMAX network, the coverage radius is approximately 600 m. In the case of a fix network this value is of approx. 1.000 m, it means that the coverage area for the same BS is reduced to 36 %. Then when a mobile network is considered, 3 times more BSs than in the case of a fix network, are necessary in order to cover the same area. For this reason is very important to estimate in advance if the mobile service is going to compensate the significant increment caused in the investment. For sure new services are coming, and this situation can change. But also different phases in the development of a broadband wireless network can be defined. The operator can start by

deploying a fix WiMAX network (based in the mobile standard IEEE802.16e), in future by adding new BSs to the same area can then promote and sale mobile services, if the market accepts and pays for them.

Most of the time a nomadic service is what the customer requires, and a real mobile service is not intensively used. The cost of deploying a good quality nomadic network is quite similar to the one required for a fix network (an amount of extra capacity has to be considered in the case of nomadic networks to accept new users that are not currently in the area of a given BS). A good quality nomadic network can be a good alternative, at least to start the development of a broadband wireless mobile network.

3.2 Using Beamforming or Not

To use Beamforming or not, is another important decision to develop this kind of networks. The objective here, is not to discuss about the advantages and disadvantages of beamforming in general, but to discuss about the performance of commercially available beamforming implementations.

Beamforming plus Space Time Coding (STC) achieve performance improvements between 3,75 dB and 16 dB compared with simple MIMO-STC, ("MIMO A"). These improvements vary depending on the velocity of the mobile terminal (16 dB for a stationary or pedestrian and 3,75 dB for a high mobility scenario). Between different approaches to beamforming, the most efficient beamforming technique is "Adaptive Beamforming".

Not all vendors agree on the convenience of deploying a network with beamforming capacity, some of them argue that the control information (for the case of WiMAX) is delivered without beamforming, and then the coverage area will not be extended by using beamforming. It is not completely so, because usually the uplink is the limitation in the coverage area, and then, by improving the capacity of "listening the subscribers" (providing 9 dB of uplink gain) beamforming will increase the coverage area.

By "improving" the signal, the number of BSs (number of sites) needed to cover the same area is diminished, usually to 2/3 of the number of sites needed with simple MIMO techniques. This has an important impact in OpEx (Paolini, 2010) (the impact in CapEx, is not always diminished, because these BSs are more expensive than simple MIMO ones).

3.3 Number of Sites

In Figure 1, an example of the distribution of CapEx for a WiMAX network is provided. These percentages vary from network to network, but usually there are some common points to care.

Usually the most significant item is "Last Mile" (BSs). In this case the best option is not to reduce the CapEx of this item, but to find a good compromise between the price for this item and the associated OpEx. As it was discussed in Section 2.2, usually cheap BSs are associated to low spatial diversity order, what results in the need of more sites and then an increased OpEx, this effect can be observed in Figure 3.

As it was discussed in Section 2.1, CPEs play an important role, because of the CapEx associated to this item. Some alternatives to decrease the CapEx for this item were already discussed.

Another important item is "Transmission" (backhaul and backbone as it was discussed in Section 2.3). To decrease this item, in LTE for example, the use of MMW is considered. Being less expensive (the associated CapEx and OpEx) and quicker to deploy, MMW is considered as a good alternative for developing the backhaul in LTE networks.

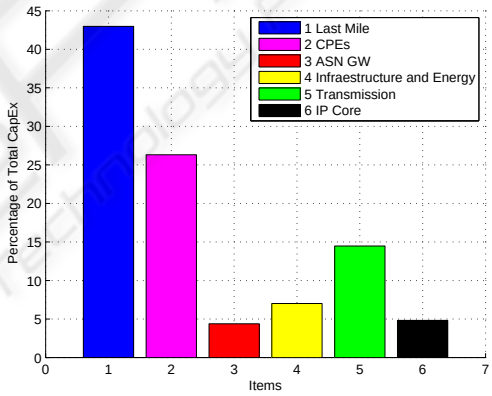

Figure 1: Percentages of the total Capex for each network component.

Exist different perspectives between vendors and operators. Usually vendors are not worried about the OpEx to maintain a network. Then diminishing the CapEx can be their focus, but from the side of operators, both expenditures has to be considered. In the market there are some BS options which implies lower CapEx, but in Figure 3, how this initial advantage is compensated with time can be observed, there the comparison for two technologies of two different vendors is shown. Some times by making an initial investment a little bit more expensive a higher efficiency network (with higher spatial diversity order, for example) can be deployed.

Considering OpEx (see Figure 2), usually "Internet Access" has an important influence in the total OpEx. Generally the operators try to obtain a good price for these item from the international carriers,

but there are not so many alternatives, then it is a relatively simple factor to optimize. One alternative to diminish this factor is to use “cache systems” in order to locally store some Internet content which is often accessed by subscribers.

Another component of OpEx is the “Spectrum Taxes”. This is an important factor when the operator has a mainly wireless network (wireless access, backhaul and backbone). In this case, at least for backhaul, MMWs represent a good alternative due to “light licensing”. As it was discussed previously, MMWs are also a good alternative from the point of view of CapEx. Besides their throughput capacity, the mentioned characteristics become MMWs in a good candidate as a backhaul technique in present and future wireless networks. Another way of diminishing this factor is by using BS technologies with high spatial diversity order, in this way less sites are needed, and then less backhaul links has to be payed.

When a wireless network is deployed, is common to use the top of high buildings to install BSs. Usually the operator pays a rent for using this space in the roof of the building. The “Site Rents” amount depends mainly on the city, but an effective way of diminishing this factor is to diminish the number of sites, and in this way the use of high spatial diversity order BSs, is a way of using less sites to offer the same coverage. Is worth to mention that usually the throughput capacity is not the determinant factor in WiMAX and LTE networks, usually the number of BSs is determined by coverage necessities more than by capacity necessities.

Finally, energy is also diminished by using less sites to deploy the wireless network. All this considerations are important ones when the operator has to decide between different vendors for the Last Mile (access) technology, as it was discussed, higher spatial diversity order technologies have several interesting advantages.

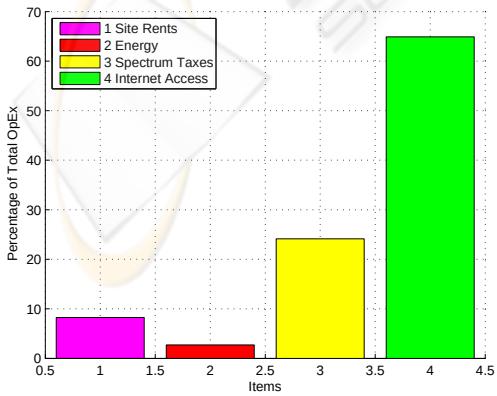

Figure 2: Percentages of the total OpEx for each item.

In Figure 3, the economical evolutions of total expenditures in 10 years for two network alternatives are compared. The alternative labeled as “Low CapEx” corresponds to a wireless network deployed with a Last Mile technology with low spatial diversity order. The alternative labeled as “High CapEx” uses a Last Mile technology with higher spatial diversity order. In this figure, the different economical efficiencies of each alternative can be observed.

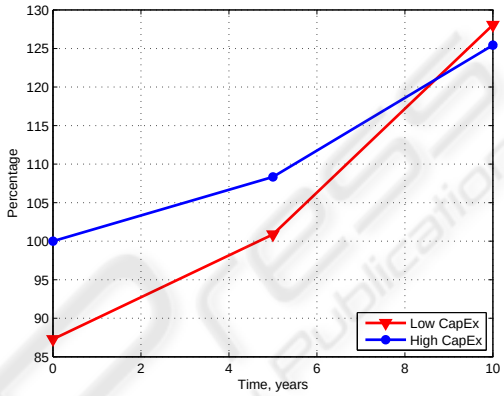

Figure 3: Economical evolution for two alternatives with different efficiency.

3.4 Financial Conditions

Financial conditions are another very important aspect to consider. This one can be the difference between a viable or not viable project. The exportation of these technologies is an important issue for any country, and usually banks and governments participate in the definition of the financial conditions that later the vendors can offer to operators. Is important for any government to be fully conscious of the importance of empowering its “knowledge industry”, because the success in this area has an accumulative effect in the economical development of a country.

3.5 WiMAX versus LTE

Usually this comparison is contaminated with particular interests, if one operator is not considering to deploy WiMAX, it seems reasonable to discourage WiMAX deployments, because they could be a dangerous competitor for 3G for example.

Another factor that makes this comparison difficult is that both technologies are in very different stages, WiMAX is a commercial reality today, while LTE is in the phase of tests, trials and promises.

What is clear is that both technologies have different temporal opportunity windows. Today WiMAX is probably the best alternative and in some years LTE

could occupy this position. One question is: by the start of LTE services, how many WiMAX users, satisfied and with a medium term contract will be?. This could affect the success of LTE in certain regions.

Probably the decision for many operators is related with legacy technologies, in the case of LTE an important effort in backward compatibility with typical legacy technologies as WCDMA and GSM is done (Beming et al., 2007). It could be a reason to wait for LTE instead of deploying a WiMAX network now. But in the mean time, operators who take the decision of deploying WiMAX networks will have important advantages to offer.

LTE has a very simple architecture, but it is not so different from WiMAX one, and both are based in OFDM also. Concerning to LTE performance, a good reference is the work made by the Heinrich-Hertz-Institute in Berlin[5]. In this work the performance of a LTE test bed deployed in Berlin is evaluated. Several similarities with WiMAX coverage and performance can be found there.

4 CONCLUSIONS

Maybe it is useful to make the network more asymmetric, less power and gain in CPEs and more power and gain in BSs. It makes the network more expensive, but cheaper CPEs (with less gain) can be used. Then more subscribers and services can be attended by the network. As it was discussed, the cost of CPEs is still a bottle-neck in the development of WiMAX networks. A more asymmetric network will increase the problem of having a reduced uplink, but with the evolution and popularization of beamforming it can be compensated. By using beamforming the BSs are able of "listening better", which is very good for weak subscriber signals.

After analyzing the impact of CPEs in CapEx, is clear that the alternative of being bought by the customer (usually in an embedded device) is well seen by operators, and good for the business. Thinking in the evolution of IPv6, and the promised explosion of devices connected to the network, WiMAX and LTE can result an excellent alternative to access these devices. This could result in an important price decrease of WiMAX and LTE chipsets for CPEs.

NGN concepts make the development of new services easier and open to professionals of different areas (not only telecommunication experts). This fact and the popularity of SCEs augur the development of an interesting set of new services in next years, increasing the competence in this area.

Another important consideration related with the deployment of this kind of networks, is to decide if a mobile or simply a nomadic network is going to be deployed, at least as the first phase of the project. Assuring a good quality mobile service increases the deployment costs, compared with a good quality fix or nomadic service.

As it was discussed, the spatial diversity order of BSs play an important role in OpEx. This has to be considered at the moment of selecting a Last Mile technology.

[5]http://www.nokiasiemensnetworks.com/sites/default/files/document/LTE_measurement_A4_1302_0.pdf

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