PROPOSED APPROACH TO FIXED-WIRELESS BROADBAND NETWORK DEPLOYMENT AND SERVICE PROVISIONING IN SINGAPORE

BROADBAND WIRELESS SYSTEMS

TECHNOLOGY SURVEY AND COMPARISON

IDA CONSULTATION DOCUMENT

31 March, 2000

Contents

1 PREFACE

In all kinds of telecommunication networks fixed radio technologies have traditionally played an important role, especially if right of way constraints, adverse terrain conditions and speed of deployment are the driving forces. For the established point to point wireless solutions, these factors have created a stable and steadily growing market.

Much higher expectations and market forecasts have been anticipated for the so-called broadband point to multipoint (PmP) systems substituting wired solutions with the same service spectrum (voice, data and video) and transmission quality whilst offering the well known advantages of wireless technology. Typical problem areas in this respect are the availability of sufficient frequency resources and the selection of efficient multiple access schemes which address the various propagation issues, especially where the antenna design plays an important role.

After some years of regulatory activities in several countries we now finally have arrived at a point where real global deployment is about to start. Germany is a good example for this process, because recently about 18 new operators succeeded in getting operating licenses in different microwave frequency bands after a long and complicated selection procedure. Optimistic press statements even saw a new "boom" or "goldrush" era in the local loop offering the new operator unlimited access to a customer base which up to now has been fully in the hand of the incumbent. Such a bright future perspective of course also activates all major suppliers of BBWLL technology - in the meantime more than a dozen - a tough competition is being expected. For the new operator not only commercial but also technical aspects play an important role. This is mainly due to the fact, that the highly innovative BBWLL technology today does not offer a standardisation of the air interface in terms of interoperability - such as in the world of mobile cellular or cordless telephony solutions - all available systems have proprietary air interfaces. A technology decision therefore is consequently a supplier decision. Of course, all suppliers see their individual solution as the leading one, making a system decision a complex task. Therefore, this paper tries to highlight the major decision parameters in a neutral way taking into account experiences gained up to now in other countries where such deployment is already under way. One of the major results is that not only equipment parameters are the decision drivers but that deployment aspects can play an even more important role.

2 PLANNING ASPECTS

2.1 What kind of frequencies and bandwidths are available?

Worldwide, a whole lot of frequency bands have been opened for BBWLL applications during the past years. Due to the fact, that we are talking about fixed radio applications (no mobility features), higher microwave frequencies (above about 2 - 3 GHz) can be used. As a major advantage, much more absolute bandwidth is available as compared to mobile cellular systems. This is the major prerequisite to run a successful business case with broadband (multiservice) systems serving many customers in the same area with several operators in parallel. In Europe nowadays three major bands have to be mentioned: the 3.5, 10 and 26 GHz bands, a band around 32 GHz will follow soon, in North America the activities have been focused around 2.5 GHz (MMDS) and 28 GHz (LMDS). All these bands are licensed bands, the operator generally owns the exclusive right of use. Unlike in North America where complete big blocks of frequencies (e.g. up to several hundred MHz in the 28 GHz region) are auctioned to a limited number of operators or even only to a single one in an area, the European allocations generally are organised in a (symmetrical) duplex arrangement and the two spectrum blocks are further subdivided in smaller portions (the so-called channels). Each operator can expect to get one or two (sometimes up to four) such channels in the frame of an auction or a selection process conducted by the regulator. Typical channel bandwidths are 2x14 MHz (6 channels @ 3.5 GHz) or 2x28 MHz (18 channels @ 26 GHz). These channel arrangements and additional RF parameters (e.g. transmit power, receiver sensitivity, spectrum masks and antenna parameters) have been specified by the European regulations bodies (ETSI/CEPT). This allows coexistence of different operators with different technologies in the same area, a major prerequisite for competition. Unfortunately, not all air interface technologies support unrestricted operation in the adjacent channel. In Germany, therefore, the regulator had to establish guard bands of one channel each. In terms of efficient spectrum utilisation, this is of course an insufficient solution. In any case, a channelized approach requires a much higher spectrum efficiency of the air interface than a block allocation.

Figure 1 shows the current frequency allocations within the different frequency ranges:

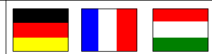
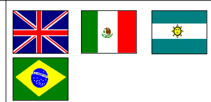
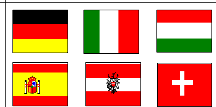
Band	Frequency Allocation	Typical Cell Size	Typical Total Capacity	Major Regulations (Mid 1999)
3.5 GHz (CEPT)	Channel BW: 14 MHz Duplex: 100 MHz	10-15 km	900 Mbit/s	
10.5 GHz (CEPT)	Channel BW: 30 MHz Duplex: 350 MHz	5-10 km	2.2 Gbit/s	
26.0 GHz (CEPT)	Channel BW: 28 MHz, Duplex: 1008 MHz	3-5 km	7.5 Gbit/s	
28.0 GHz (CEPT)	Channel BW: 28 MHz, Duplex: 1008 MHz	3-5 km	7.5 Gbit/s	
28.0 GHz LMDS (FCC)	Block Allocation 850 MHz 150	3-5 km	4.5 Gbit/s	
28.0 GHz LMCS	Block Allocation 500 MHz 500 MHz	3-5 km	4.5 Gbit/s	

Figure 1: Frequency allocations for Broadband-WLL.

Although more stringent than the US/Canadian arrangements, ETSI/CEPT channelised recommendations lead to a much better market acceptance because the prescribed duplex separation and the tough spectrum mask requirements guarantee the coexistence of different systems within the same frequency band. This enables the regulatory bodies to grant more licenses to more operators within the same geographical area, thus encouraging a competitive commercial environment that would otherwise be difficult to achieve within the framework of a block allocation of radio spectrum.

In some countries two of the band allocations are available, one at lower frequencies and the other one in the millimetric range (e.g. Germany: 26 and 3.5 GHz) thus creating a perfect synergy between very high capacity (short range) and medium to high capacity (long range) deployment strategies. A major prerequisite for such system solutions is a highly efficient radio technology not only relating to modulation/demodulation but also to the selection of the optimum multiple access scheme coupled with highly linear microwave technology.

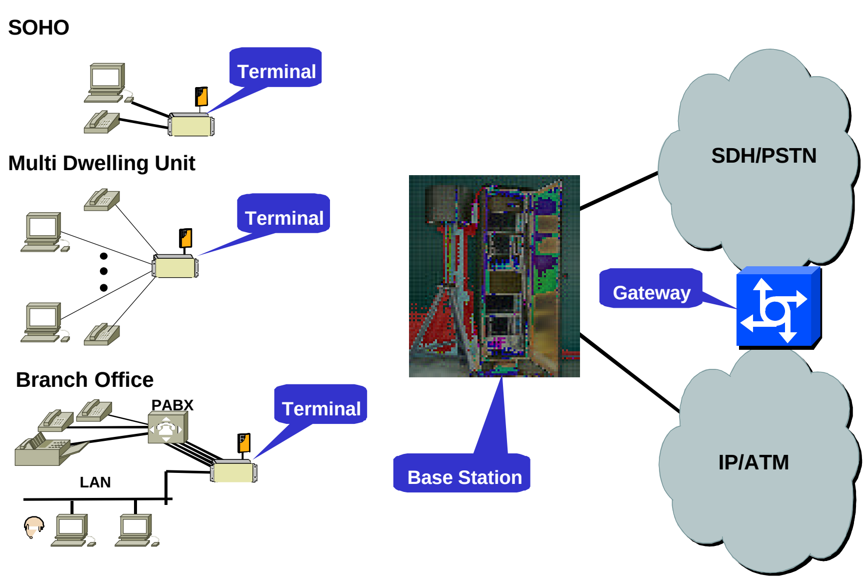
The availability of lower frequency bands within the ETSI/CEPT recommendations also allows for effective deployment of BBWLL systems within tropical and sub-tropical regions. The propagation characteristics of 3.5 and 10.5 GHz band systems address the high rain index factors which physically limit RF performance at 26 and 28 GHz, irrespective of the chosen regulatory environment.

2.2 What kind of customers are in the focus ?

The last mile of course is highly attractive due to its tremendous customer base, which up to now mainly has been controlled by the incumbent. Installing an own (especially wireless) access infrastructure therefore is an interesting alternative to strategies like call by call or unbundled access. Nevertheless, also wireless access technologies have to bee seen under realistic boundary conditions. The large initial infrastructure investment has to be aligned with a carefully optimised service offering and a clever tariff strategy. Starting with the residential customer on a large scale basis, therefore, seems to be the wrong entrance strategy. A much more promising initial customer base is given by SOHO and branch office customers or so-called multi-dwelling scenarios in dense traffic areas which can be served with a high valued mix of telecommunication applications. Covering larger areas with lower traffic could be envisaged in a later stage, but always requires a certain customer density to be commercially successful, this is not always the case.

In figure 2 a typical structure of a wireless access system is shown.

Figure 2: structure of a WWL-Network.



2.3 What kind of service spectrum has to be offered ?

Establishing an own access infrastructure generally leads to a considerable initial investment for the operator. This is even true under the assumption that most of the equipment offerings today feature a "pay as you grow" capability, i.e. they are modular. The service offering and the associated tariff strategy, therefore, are the important parameters in order to reach the threshold customer base quickly. Investigating corresponding model scenarios and taking into account experiences from already installed systems the answer is very clear: the wider the offering, the higher the quality, the better. Such a suitable service offering basically comprises the classical services like POTS, ISDN (in several countries) with unchanged technical specifications (e.g. minimum delay) and leased lines with constant or varying transmission capacities. This is of special importance in order to be compatible with the installed base of customer premises equipment. On top, higher valued services are mandatory, the favourite of course nowadays being fast Internet access with a transmission speed which is at least one order of magnitude faster than the classical dial in access via modem. This is the perfect prerequisite for numerous IP based applications such as browsing, download, videoconferencing, video on demand, teleworking, E-commerce and so on.

It is especially important in the frame of a technology and vendor selection process, that the equipment offers the necessary interfaces directly. This seems to be self evident, but the reality is, that not every equipment offering can meet these requirements. Requirements for additional third party customer premises equipment normally lead to unexpected surprises, especially if it comes to network management. Full end-to-end network management with an integrated approach is one of the major prerequisites for a commercial success and is very often highly underestimated. The reason is very simple: operating costs are by far the dominant costs during the system lifetime.

2.4 What kind of transmission rates and system capacities are required ?

In order to evaluate the necessary total transmission capacity of a broadband wireless local loop network, first, the traffic requirements of the individual terminals must be known. Typical parameters of such a traffic requirement evaluation are the mean and peak rate of the individual connections and the number of subscribers in a given area. It is obvious, that with a spectrum offering of only 28 MHz duplex (in the European case) only a corresponding traffic throughput of about 30 -34 Mbit/s can be reached with conventional modulation schemes. Even if only bursty traffic with a high difference between mean and peak traffic rate is considered (e.g. web browsing) and if dynamic bandwidth allocation is used only a limited number of subscribers can be served. For traffic with a more or less constant rate (e.g. leased lines) this problem even becomes more obvious.

Therefore it is necessary to increase the net modulation efficiency (measured in bit/s/Hz) and the area capacity (measured in bit/s/Hz/area) by using higher order modulation schemes and at the same time utilising a microcellular concept (i.e. several overlapping cells or sectors). But this strategy leads us into a principle dilemma: the limiting factor in a cellular network is self interference inhibiting the utilisation of any arbitrary high level modulation scheme due to the higher interference sensitivity. It can be shown, that modulation schemes with more than 16 levels even decrease the overall efficiency. A possible solution can be found in utilising adaptive modulation with adaptive frequency planning in a multicellular approach. Thus, optimum spectrum efficiency can be utilised, where the interference is low, in case of interference more robust schemes are applied, in extreme cases decoupling by changing the carrier frequency to an unobstructed portion of the spectrum is applied. Modern modem technologies permit to use these counteractions even during operation without any traffic interruption. Such technologies lead to area capacities which can be 10 to 20 times better than with conventional approaches (area efficiencies of about 10 - 20 bit/s/Hz/area). Another major prerequisite for such performance is the utilisation of highly sectored base station antennas with a high spatial decoupling to the neighboured sector and the use of orthogonal polarisation. Depending on the frequency band, cell radii of about 10 - 15 km (@ 3,5 GHz) and 3 - 5 km (@ 26 GHz) can be achieved.

2.5 What are the key parameters for deployment ?

Besides the a.m. optimisation strategies which are quite complex, there is another very simple rule for successful deployment of wireless access networks. Due to the physics of electromagnetic waves we need LOS (line of sight) between the base station and the terminals. Numerous planning processes in city environments have shown, that utilising a single base station for area coverage, at the average only 40 - 50 % of the customers are visible. This percentage even decreases with increasing cell radius. Normally, such a LOS probability is not sufficient to run a successful business case. Proposals, to increase the base station height dramatically lead to substantial ground reflections and are highly counterproductive. An alternative, again, is given by the a.m. multicellular concept: the coverage area is illuminated from several (smaller) sectorized base stations according to the required traffic and coverage specifications. As experiences have shown, nearly 100 % of coverage in a typical city environment can already be reached with 3 - 5 base stations with 2-3 sectors each. Of course, the higher equipment and site cost has to be taken into account. Due to reciprocity, the terminals at the average have LOS to more than one base station. This enables a reconfiguration in the case that new buildings are erected during the system lifetime.

3 TECHNICAL ASPECTS

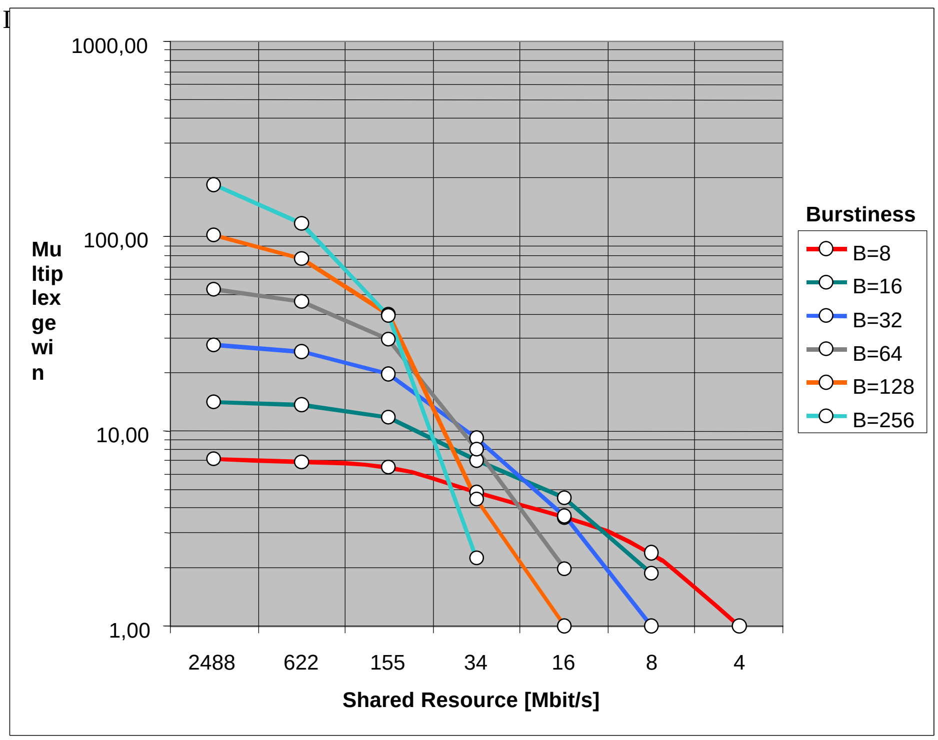
3.1 Channelized versus packetized

Today's telecommunication networks generally are heterogenous i.e. consist of a more conventional circuit switched part handling voice and leased line traffic and a packet switched part handling the data and especially Internet traffic. Circuit switched networks have the advantage to provide QoS by definition (physical channel during the connection), packet or cell oriented networks either operate according to best effort principles (IP based networks of today) or use specific means to ensure QoS (ATM networks). Wireless networks have to be compatible with these boundary conditions by a seamless integration into all types of existing networks. It is therefore important to provide not only the right customer interfaces but also a variety of network interfaces and protocols. These are either synchronous interfaces (SDH and/or SONET with data rates of STM-1, STM-4, OC3, OC12) or IP based interfaces (100 BaseT, Gigabit

Ethernet) offering network protocols like V5.1, V5.2, VB5.x, ATM UNI or TCP/IP). With such a flexibility, heterogenous networks or "pure" networks (like IP and/or ATM based) can be offered.

One of the major advantages w.r.t. packet or cell based networks is the capability of dynamically concentrating bursty traffic thus offering a very efficient utilization of network ressources. This type of concentration (the statistical multiplexing gain) is of course especially important for radio access networks. Usual calculations assume a traffic peak to average ratio of about 1:20. If such a concentration could be used, the advantage in respect to circuit switched systems (with possible concentration factors of about 3 - 5 depending on user activity and blocking rate) is obvious. Unfortunately, the boundary conditions for a high statistical multiplexing gain in wireless systems with their limited bandwidths are by far not as favourable as in fiber based systems. It can be shown with traffic theory, that the statistical multiplexing gain decreases with decreasing ressource size. Some computed values can be found in figure 3:

Figure 3: Statistical multiplexing gain.



- **RT-VBR-Traffic**
- **CLR : 1E- 6**
- **no buffering**
- **Mean Data Rate 64 kbit/s**
- **Peak Data Rate: up to 16 Mbit/s**

3.2 TDMA versus FDMA

The communication between a central station (the base station) with several users (the terminals) requires a so-called multiple access scheme. The users share a common resource according to predefined rules. The two classical schemes (TDMA: time division multiple access) and FDMA (Frequency Division Multiple Access) utilize either ressources in the time domain (TDMA) or in the frequency domain(FDMA). Other possible schemes like CDMA (Code Division Multiple Access) and SDMA (Spatial Division Multiple Access) are currently not used for BBWLL.

Information theory tells us, that both TDMA and FDMA are fully equivalent in principle. But if it comes to real implementations, there are a lot of differences depending on the individual technical solution and the deployment boundary conditions.

3.2.1 Overview TDMA systems

Modern TDMA systems normally use a continuous broad downstream (base to terminal) carrier, containing all information for the corresponding sector. The uplink is operated in a burst mode, i.e. the terminals are transmitting only during discrete times monitored by a MAC (Media Access Control) protocol. This method requires a careful terminal synchronization. Within the parameters of the TDMA frame, access to individual timeslots or cells/packets is very fast. This advantageous feature has to be seen under the aspects of a considerable MAC and synchronization overhead as well as the inevitable delay. Delay requirements in the order of 1 - 2 ms as normally required by operators for the last mile portion of the total network cannot be met. This may be acceptable for non real time services but generally is critical if a high emphasis is given to time critical services. To achieve a considerable statistical multiplexing gain, a sufficient shared ressource size is required. This means for TDMA that a high carrier bandwidth is needed, because the TDMA carrier is the ressource. Again, this is a typical dilemma situation: a high carrier bandwidth means, that a considerable continuous portion of the spectrum is needed, higher order modulation schemes are only feasible up to a certain level. In the extreme case this means a utilization of the complete RF channel without any possibility to reuse the frequency. If frequency reuse is required, smaller carrier bandwidths have to be chosen, decreasing the potential of multiplexing gain. TDMA systems, therefore are a good choice if residential like customers are to be served featuring only moderate real time requirements and if the system capacity requirements are only moderate.

3.2.2 Overview FDMA systems

FDMA is working with continuous (normally symmetric) carriers in both directions. Any link is instantaneously providing the required capacity. This leads to the minimum delay, which is only limited by the channel coding algorithms. The times where FDMA could only provide constant transmission rates are gone. Modern adaptive modem technology can change data rates, modulation schemes, coding, carrier frequency and spectral power within milliseconds during transmission without introducing bit errors. Such a technology enables an adaptive optimization of the channel parameters on a per link basis, which is in principle impossible for TDMA. The price to pay is the number of modems (2xn modems for FDMA in comparison to n+1 modems for TDMA). FDMA therefore requires a very high degree of VLSI integration which is feasible today. Speed improvements of VLSI and DSP technology even allows to implement several modem functions within the same hardware.

3.2.3 CDMA

(Code Division Multiple Access) is a more modern scheme, still under further study and investigation for real broadband operation. Basically, CDMA is foreseen for environments with unfavourable propagation conditions such as mobile systems or systems with a high degree of reflected signals and/or interference. By its very nature, the CDMA access scheme is very robust against such impairments because the spectral spreading of the original data signal creates immunity against narrowband and uncorrelated interferers. The price paid for this robustness is bandwidth. Therefore, such an application is mainly useful at lower frequencies, together with very simple receiving equipment. Furthermore, the limited availability of frequencies only allows the use of low user data rates if a significant signal spreading is required. As a consequence, such systems are not primarily suited for BBWLL applications with high system capacities.

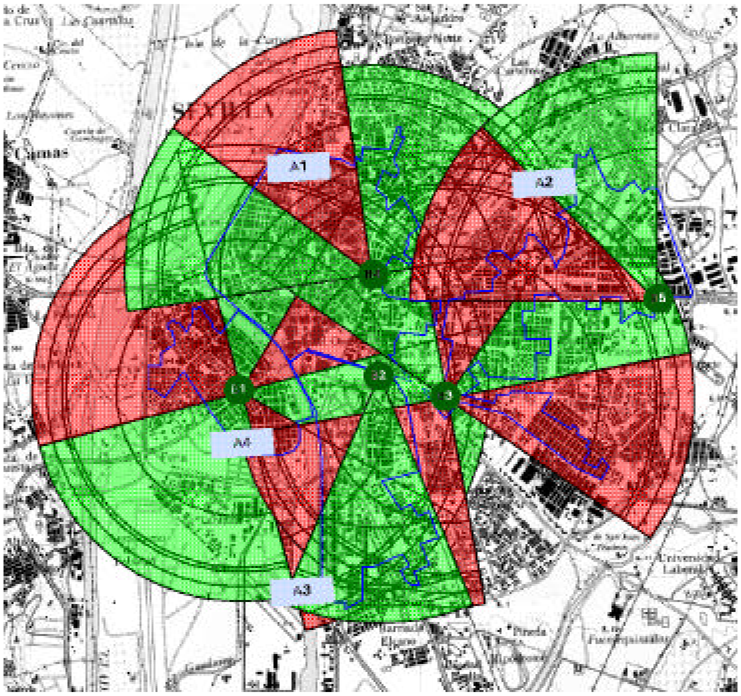
3.2.4 SDMA

(Space Division Multiple Access) can be used directly as a multiple access scheme by assigning adaptive antenna beams to users or by using spatial filtering technology in order to improve the C/I ratio, especially in a cellular environment. Due to its inherent orthogonality to all of the above schemes (FDMA, TDMA and CDMA), SDMA can be used in each case and can improve the corresponding systems' capacity considerably. Fortunately, this can be used completely independent of the transport technology within the radio kernel.

3.2.5 Single Carrier versus Multicarrier

FDMA systems in principle are multicarrier systems, because any link naturally has its own carrier. The dynamic organization in the spectral domain is monitored on a per sector basis by a so-called radio resource management (comparable to the MAC protocol in the time domain). Furthermore, a multicellular frequency control optimizes the ressources in a multicellular environment. Any carrier occupies only a small portion of the overall spectrum (depending on actual data rate and modulation scheme) and therefore is highly robust against channel impairments which are considerably higher than for point to point systems. This is mainly due to the relatively broad base station sector antenna patterns (e.g. 90° or 45 °) and the cellular environment with a certain interference potential. Selective fading - as normally experienced with point to point systems - does not play a significant role. If higher terminal data rates are required, several carriers can be groomed together temporarily.

See figure 4 as an example for a multicellular system:



5 base stations
17 sectors
polarisation reuse
dedicated frequency planning
10 sectors fully decoupled
7 sectors interfering

Result for FDMA:

single 28 Mhz channel
dedicated frequency planning
adaptive modulation

Result for TDMA:

two 28 MHz channels
dedicated frequency planning not possible
same (robust) modulation for all TDM carriers

Figure 4: Multicellular system.

TDMA systems offer the choice between single or multiple carrier operation. Consequently, nearly all combinations can be found in current product offerings. In single carrier systems occupying a complete RF channel, the advantage is a sufficient shared ressource, but the compatibility with a cellular environment is bad due to the limited frequency reuse. Even if the second polarization is used, at least two sub bands are needed, in the case of single polarization operation even four. As a logical consequence, some systems offer two or four carrier solutions, some other solutions even contain up to 16 TDMA carriers in a single 28 MHz RF channel. This increases the chance for a statical frequency reuse, but the shared resource decreases with increasing carrier numbers to e.g. 16, 8 or even 4 Mbit/s. The statistical multiplexing gain or the number of simultaneously operating terminals decreases accordingly.

Multicarrier systems are often said to require unreasonable high efforts in terms of linearity in the analog RF part (still the big cost driver). This is only partly true. Base stations, in fact, require a high linearity due to multicarrier operation. At the terminal side (single carrier operation) the situation is much more relaxed and can even turn into an advantage because the terminal is normally operated in single carrier mode. Depending on the number of carriers of an FDMA system, the output power of a terminal can be considerably lower as the output power of the base station (up to 20 dB).

4 ANTENNA TECHNOLOGY

Important considerations for BBWLL systems are the antennas, both at the base station and at the terminals. Adverse propagation effects such as multiple reflections and interference – occuring with a much higher probability in cellular and area coverage situation – have to be counteracted by appropriate spatial filtering technologies. Key elements are therefore antennas with directive low sidelobe and low crosspolarisation beams for a terminal application and corresponding sector beam arrangements (with different sector beamwidths) at the base station.

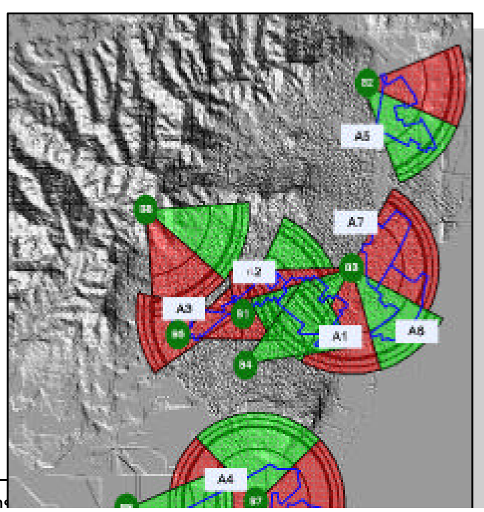
Conventional solutions like centre fed parabolic antennas (terminal) and horn type antennas (base station) only offer limited capabilities in terms of sidelobe suppression and pattern steepness and therefore lead to a higher probability for the presence of unwanted and interfering signals.

5 DEPLOYMENT ASPECTS

Deployment aspects of PmP systems are often underestimated in terms of their influence on area capacity and, as a consequence, commercial impact. One of the major prerequisites for a successful commercial deployment is sufficient coverage which, at higher frequencies, is mainly determined by the LOS (line of sight) availability between base station and terminal locations.

Typical arrangements show centralised (sectorised) base stations illuminating a more or less circular area with single non-overlapping beams. LOS analyses of such arrangements show that in the majority of cases the LOS coverage is rather poor (< 60% or even less). Taking into account a certain market penetration (with respect to services) such additional limitations may lead to insufficient business case justification. This is due to the fact that a sparsely filled cell or sector automatically leads to a high connection (link) prices due to the substantial cost difference between terminals and base stations.
Therefore, so-called offset base station arrangements where several base stations illuminate the same area fully, or at least partly, are the better solution - despite the higher cost of the overall scenario (Figure 1).

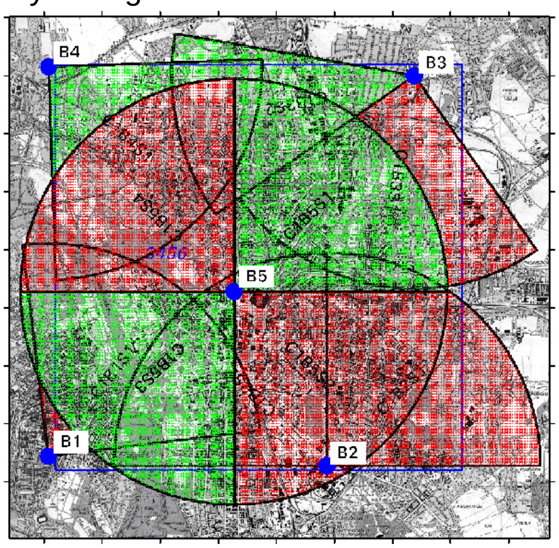
Fig. 1: Configuration Example (partly overlapping beams)



Changing polarisation from sector to sector by an appropriate sector transceiver design can normally de-couple a certain subgroup of beams. For fully overlapping beam scenarios additional frequency decoupling is necessary. In cases where two or more RF channels are available, or in case of block frequency allocations, this is a trivial issue. The reality, nevertheless, shows that in many systems utilising such high bandwidth or multiple channel strategies a substantial oversubscription occurs. This can lead to long term regulation and licensing processes influencing the time to market rollout in a negative way.

As an example, Fig. 2 shows how a 26 GHz network deployment can be achieved where extensive use of additional frequency decoupling with a dynamic FDMA system is employed (see section III a). This leads to a very high area capacity (reuse 99% in this case) and an extremely high LOS coverage ratio (more than 90% in the multi-illumination areas) by using only a single 28 MHz RF channel as defined in the ETSI/CEPT recommendations. Furthermore, the excellent spectrum performance of such multicarrier systems permits the full utilisation of the adjacent RF channel within the same geographical area without introducing guard bands.

Fig. 2: Configuration Example (fully overlapping beams). All sectors utilising the same channel, colours indicate polarity changes.



6 CONCLUSION

The selection of a suitable regulartory environment for a BBWLL system is a non-trivial task. The chosen framework and access scheme requires careful optimization of several parameters relating to network aspects, traffic theory, individual system parameters and performance. Furthermore, the radio network planning, microwave technology, operational, commercial and competitive aspects need to be considered. BBWLL is a challenging and innovative field of modern telecommunication networking with a tremendous potential. It will be interesting to monitor to what extent the expectations of BBWLL can be met.