Fixed Broadband Wireless Access: State of the Art, Challenges, and Future Directions

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ABSTRACT

This article provides an overview of fixed broadband wireless access technology. Focusing on the band below 3 GHz, we describe BWA service and carrier needs, deployment scenarios, architectural requirements, physical layer, medium access control, and radio link protocol requirements. We characterize fixed BWA channels, outline the major challenges of fixed BWA, and study requirements for future BWA systems. Finally, we show that the use of multiple antennas at both ends of a fixed wireless link provides significant leverages.

INTRODUCTION

The rapid growth in demand for high-speed Internet/Web access and multiline voice for residential and small business customers has created a demand for last mile broadband access. Typical peak data rates for a shared broadband pipe for residential customers and small offices/home offices (SOHO) are around 5–10 Mb/s on the downlink and 0.5–2 Mb/s on the uplink. This asymmetry arises from the nature of Web traffic and its dominance. Voice and videoconferencing exhibit symmetric traffic. While the evolution of Internet services and the resulting traffic is hard to predict, the demand for data rates and quality of broadband last mile services will certainly increase dramatically in the near future.

Broadband access is currently offered through digital subscriber line (xDSL), cable, and broadband wireless access (BWA). Each of these techniques has different cost, performance, and deployment trade-offs. While cable and DSL are already being deployed on a large scale, BWA is emerging as an access technology with several advantages. These include avoiding distance limitations of DSL and high costs of cable, rapid deployment, high scalability, lower maintenance and upgrade costs, and granular investment to match market growth. Nevertheless, a number of important issues including spectrum efficiency, network scalability, self-installable customer premises equipment (CPE) antennas, and reliable non-line-of-sight (NLOS) operation need to be resolved before BWA can penetrate the market successfully. Wireless services in the 24–48 GHz band such as local multipoint distribution services (LMDS) are suitable only for large high rise corporate offices where direct LOS links well above foliage can be deployed. In this article we consider the sub-3-GHz (multipoint distribution services, MDS, multichannel multipoint distribution services, MMDS, and wireless communications services, WCS), and unlicensed bands where the foliage penetration and NLOS operation needed to reach homes is feasible. Figure 1 shows the growth in subscriber bandwidth availability.

The remainder of this article is organized as follows. The next section discusses BWA service needs, deployment scenarios, architectural requirements, and challenges in fixed wireless networks. We then characterize fixed BWA channels below 3 GHz. The article goes on with a study of the physical layer, medium access control (MAC) layer, and radio link protocol (RLP) requirements of fixed BWA systems. We then describe possible leverages of fixed BWA resulting from the use of multiple antennas at both ends of the wireless link. The last section outlines future challenges, and discusses current standardization efforts and industry trends.

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SERVICE NEEDS, DEPLOYMENT SCENARIOS, AND ARCHITECTURAL REQUIREMENTS

BWA SERVICE AND CARRIER NEEDS

Typical BWA services include Internet access, multiline voice, audio, and streaming video. Quality of service (QoS) guarantees for data and toll quality voice are needed.

Carrier requirements include meeting FCC regulations on power emission and radio interoperability, scalability using a cellular architecture wherein throughput per square mile can be increased by cell splitting, low-cost CPE and infrastructure equipment, high coverage and capacity per cell which reduces infrastructure costs, self-installability of CPE antennas, and finally, evolution to portability.

DEPLOYMENT SCENARIOS AND ARCHITECTURES

We discuss three different deployment scenarios: supercells, macrocells, and microcells.

Supercells — In this scenario a large service area with a radius of up to 30 mi is covered. The base transceiver station (BTS) antenna height is typically in excess of 1000 ft, and a high-gain rooftop directional CPE antenna is needed with a LOS connection between transmitter and receiver. This is a single-cell configuration which is not scalable. The same cell frequency reuse in angle and polarization may be possible with sectorization. Due to LOS propagation, carrier-to-noise ratio (C/N) values of around 30 dB can be sustained, which makes the use of high-order modulation possible. Due to the strict need for LOS links, high coverage generally cannot be guaranteed.

Macrocells — Macrocells typically use cellular architecture with spatial frequency reuse between cells. The BTS antenna height is significantly lower than in the supercell case, typically 50–100 ft. The CPE antennas can be lowered to under the eave. Low BTS heights induce severe path loss and NLOS propagation. A cell radius of around 5 mi may be possible. Due to NLOS propagation and co-channel interference (CCI) from other cells, significantly lower C/N and carrier-to-interference ratio (C/I) values than in the supercell case must be supported, and lower-order modulation has to be used. Directional CPE antennas can still be employed. The architecture is scalable in both capacity and coverage, and high coverage is possible since NLOS propagation is supported.

Microcells — Microcells are similar to macrocells with the difference that much smaller cells (typical cell radius of 1 mi) are used. The BTS towers are lower than in the macrocell case, typically below rooftop, and may be 20–40 ft high. This architecture supports portability; therefore, the CPE antennas are omnidirectional indoor antennas. Small cell sizes offer sufficient link margin to provide indoor coverage.

The rest of the article focuses on the macro- and microcell cases.

CHALLENGES IN FIXED WIRELESS NETWORKS

We shall next outline the major challenges in fixed wireless networks and discuss the main differences between fixed broadband and current mobile wireless access networks. Essentially the quality and data rate requirements in the fixed case are *significantly* higher than in the mobile case. Due to the requirements for *higher data rates*, the link budget shrinks by roughly 15 dB assuming that fixed transmit power remains the same as in the mobile cellular case. The requirements for higher quality increase the needed fade margins for C/N and C/I by roughly 15 dB each. Taking into account that the use of directional antennas provides a gain of roughly 15 dB in link budget against noise, this translates into a 15 dB disadvantage in link budget against noise and a 15 dB disadvantage against CCI. The former means much smaller coverage or cell radius (1/5 of the mobile cell radius); the latter requires much higher reuse factors (20–30 instead of 3 in mobile) and hence 1/6 cell capacity. Hence, new sophisticated physical and radio link layers are needed in order to maintain coverage and retain a reuse factor of 3. The use of multiple antennas, discussed in more detail later, provides significant leverages in terms of link budget against noise and CCI, and seems to be a promising means to meet these requirements. Coverage influences network economics since good coverage reduces the infrastructure costs during initial rollout. Extra capacity improves network economics by delaying the need for cell splitting.

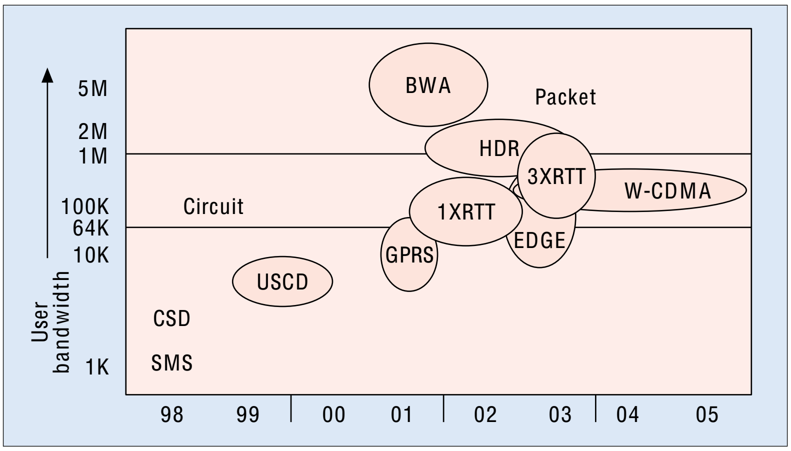

Figure 1. *Growth in subscriber bandwidth availability (source: Deutsche Banc Alex. Brown estimates).*

The spectral efficiency of a wireless network is measured in bits per second per Hertz per cell (BHC). Spectrum efficiency can be increased through aggressive frequency reuse and higher-order modulation. However, frequency reuse incurs CCI in a multicell environment. In a single (super) cell environment frequency reuse in angle is the source of CCI and depends on the sidelobe leakage of the BTS antennas and scattering from reuse sectors. Treating CCI as additive white Gaussian noise, the Shannon formula for the theoretical limit on BHC can be written as

$$BHC = \frac{L}{mK}\log_2\left(1+\frac{C}{N+I}\right),$$

where K is the spatial reuse factor, L the angle reuse factor, m an overhead factor accounting for excess bandwidth and frequency guard bands, and $C/(N+I)$ the carrier-to-interference-plus-noise ratio. In macro/microcell systems K is equal to the cluster size and $L = 1$. In supercell systems $K = 1$ and L is the num-

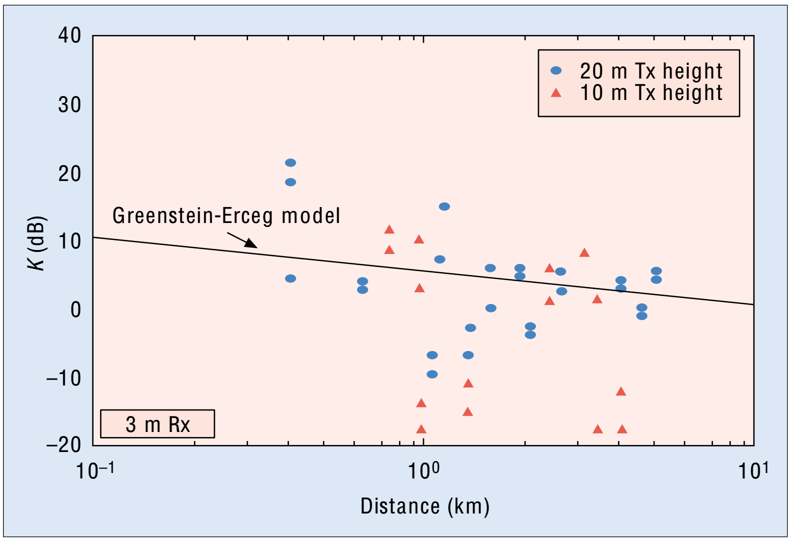

Figure 2. K-*factor as a function of distance between transmitter and receiver.*

ber of times a channel is reused in angle. Reducing K in macro/microcell systems or increasing L in supercell systems would increase BHC. However, at the same time this results in an increase of CCI and hence a decrease of $C/(N + I)$, and a reduction of the modulation order that can be sustained. In practice, the optimum trade-off between K, L, and $C/(N + I)$ depends on various factors such as target bit error rate, propagation conditions, C/N, antenna sidelobes, and diversity schemes. Typical values of BHC for current mobile cellular systems such as GSM are 0.2–0.3. Fixed BWA requirements are in the range of BHC = 2–2.5, which implies that BWA needs a significant increase in BHC.

Broadband Wireless Access Channels

Wireless transmission is limited by available radio spectrum and impaired by path loss, interference, and multipath propagation, which cause fading and delay spread. Because of these limitations wireless systems will in general offer much greater challenges than wired systems. This section discusses BWA channels, focusing on the range below 3 GHz.

Path Loss and Delay Spread

The path loss in BWA channels depends on the terrain type. In general, it is found that the COST 231-Hata model gives reasonable estimates of the path loss for flat terrain and high base station antenna heights for a wide frequency range. In moderate or hilly terrain and for lower base station antenna heights, the Hata model may not suffice, and other models may have to be used. Measurements in the 1.9 GHz band representative for the macro/microcell case have been reported in [1]. These measurements show differences in path loss on the order of tens of decibels for different terrain categories, which makes a distinction very important.

The amount of delay spread in fixed wireless channels depends strongly on the antenna characteristics. In [2] median root mean square (RMS) delay spreads for directional antennas in suburban environments of approximately 75 ns have been reported; with omnidirectional antennas in the same terrain a delay spread of 175 ns has been found [2]. The reason for the difference in delay spread for directional and omnidirectional antennas is that echoes at longer delays tend to arrive at angles farther from the direct path and are thus more attenuated by the side lobes in the case of directional antennas. Measurements conducted mostly in the 900 MHz band [3] with omnidirectional antennas in suburban, urban, and mountainous environments show delay spreads of up to 16 μs. The fade rates encountered in fixed wireless environments are between 0.1 and 2 Hz.

K-Factor

The path gain of a fixed BWA channel can be represented as having a fixed component plus a fluctuating (scatter) component. The ratio of the average energy in the fixed component to the average energy in the scatter component is called the K-factor. The value of the K-factor has significant implications in system design and performance. Generally it is found that the K-factor in fixed wireless applications can be very low, which is due to low BTS and CPE antenna heights (under the eave CPE antennas). Figure 2 shows K-factor measurements conducted by the Smart Antennas Research Group at Stanford University. In these measurements performed in the 2.4 GHz band, the transmit antenna was 10 and 20 m high, respectively, and the CPE antenna with a 50° 3 dB beamwidth in azimuth was 3 m high. It is found that the K-factor decreases significantly with increasing distance between transmitter and receiver. We note that the K-factor shown in Fig. 2 has been averaged over time and frequency. In practice, significant fluctuations in K-factor can occur due to wind and traffic. In Fig. 2 we also show the Greenstein-Erceg model for the median K-factor vs. distance [4] assuming 20 m transmit and 3 m receive antenna heights. The experimental data and the model are in excellent agreement.

To summarize, in a fixed BWA system design, very low K-factors (almost purely Rayleigh fading conditions) have to be assumed in order to provide large cell coverage and reliable operation at the edge of the cell.

Physical Layer, MAC Layer, and Radio Link Protocol

In this section, we discuss issues pertaining to the physical layer, MAC layer, and RLP of a BWA system.

The Physical Layer

Modulation — We consider three alternative modulation formats: single-carrier (SC) modulation with equalization, direct sequence code-division multiple access (DS-CDMA) with a rake receiver, and orthogonal frequency-division multiplexing (OFDM) with interleaving and coding, and briefly mention the new technique of ultra-wideband modulation (UWBM). We assume throughout that the transmitter does not know the channel.

Single-Carrier Modulation with Equalization — Several equalization options with different performance and implementation tradeoffs exist for SC modulation. Maximum-likelihood (ML) equalization yields optimum performance but is computationally very expensive. Decision-feedback equalization (DFE) is generally considered an attractive option in practice. Simpler alternatives include linear equalizers such as zero-forcing or MMSE. Linear equalization, however, does not properly exploit the frequency diversity in the channel arising from delay spread. In practice, the computational complexity of SC equalizers and the complexity required for equalizer adaptation can pose limits on the performance of SC systems in the high delay spread and/or high data rate case.

DS-CDMA — DS-CDMA uses a spreading code sequence which is multiplied into the digital baseband transmitted symbol. This spreading code sequence has a much higher rate than the information bearing symbol which spreads the symbol in frequency. A RAKE receiver can be employed to exploit frequency diversity. With increasing data rate, both the symbol rate and chip rate increase, which allows the system to resolve finer differences in the physical path delays, but results in an increased number of discrete-time baseband channel impulse response taps and hence makes an increase of the number of elements in the rake combiner necessary, which results in increased computational complexity.

Orthogonal Frequency-Division Multiplexing — OFDM eliminates the need for equalization by inserting a guard interval (cyclic prefix) which is a copy of the last part of the OFDM symbol and must be long enough to accommodate the largest possible delay spread. The transmitter and the receiver employ an inverse fast Fourier transform (IFFT) and FFT, respectively, and equalization reduces to simple scalar multiplications on a tone-by-tone basis. In OFDM frequency diversity is obtained by coding and interleaving across tones. For increasing delay spread and/or data rate, the cyclic prefix must increase proportionally so that it remains longer than the channel impulse response. Thus, in order to maintain a constant overhead due to the CP, the number of tones N must increase proportionally as well. This results in increased computational complexity due to the increased FFT size. Summarizing, the ease of equalization seems to favor OFDM over SC and DS-CDMA from a pure complexity point of view.

Ultra-Wideband Modulation — UWBM has attracted a lot of interest recently for wireless broadband communications. In UWBM, trains of pulse position modulated sub-nanosecond pulses are used to convey information. A RAKE receiver realizes path diversity. The result of the pulses transmitted across an ultra-wideband spectrum means that UWBM may be able to coexist with other narrowband systems since the interference energy per system may be small and may only increase the noise floor. Recently, UWBM has received some encouragement from the FCC. Several industry efforts are underway to commercialize the technology. So far no consensus regarding the areas of applicability of UWBM has emerged.

Hardware Considerations — From a pure complexity point of view OFDM seems to be more attractive than SC and DS-CDMA. In practice, however, OFDM signals make the system sensitive to power amplifier nonlinearities. Therefore, in the OFDM case the power amplifier cost is higher. The decision as to whether SC, DS-CDMA, or OFDM should be used is therefore driven by two factors: the cost of silicon required for the transmit and receive signal processing operations, and power amplifier cost.

Channel Coding — Channel coding adds redundancy to the transmitted data to allow the receiver to correct transmission errors. As mentioned above, in the OFDM case channel coding combined with interleaving also provides frequency diversity. Typical BWA channel coding schemes employ concatenated Reed-Solomon (RS)/convolutional coding schemes, where RS codes are used as outer codes and convolutional codes as inner codes. Soft decoding and iterative decoding techniques can add additional gain.

Synchronization — The timing and frequency offset sensitivity of SC and DS-CDMA systems is theoretically the same as long as they use the same bandwidth and data throughput. OFDM is more sensitive to synchronization errors than SC and DS-CDMA.

Link Adaptation — In BWA systems channel conditions can vary significantly due to fading. It is therefore desirable to adapt the modulation and coding scheme to the channel conditions. While voice networks are designed to deliver a fixed bit rate, data services can be delivered as variable rate. Voice networks are engineered to deliver a certain required bit rate at the edge of the cell which constitutes the worst case. Most users, however, have more favorable channel conditions. Therefore, data networks can take advantage of adaptive modulation and coding to improve the overall throughput. In a typical adaptive modulation scheme a dynamic variation in the modulation order (constellation size) and forward error correction (FEC) code rate is possible. In practice, the receiver feeds back information on the channel, which is then used to control the adaptation. Adaptive modulation can be used in both up- and downlinks. The adaptation can be performed in various ways: user-specific only, user- and time-specific, or QoS-dependent.

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An important feature of the MAC layer is the ability to perform retransmission, which allows operation at higher error rates and hence permits better frequency reuse, increases robustness, and improves TCP performance.

Multiple Access — In TDMA, multiple access is performed by assigning different disjoint time slots to different users, or equivalently the transmission time is chopped up into sequentially accessed time slots. Each user then takes turns transmitting and receiving in a round-robin arrangement. For data networks, where channel use may be very bursty, TDMA is modified to reservation-based schemes where time slots are allocated only if there is data to be transmitted. In CDMA all the users transmit at the same time with different users employing different quasi-orthogonal signature sequences. While there is little theoretical difference in terms of capacity between TDMA and CDMA, CDMA offers implementation advantages in terms of realizing signal and interference diversity. In BWA, however, *fixed spreading* CDMA is not attractive since the operating bandwidth due to a high spreading factor (typically larger than 32) becomes very high. For example, for a data rate of 10 Mb/s an operating bandwidth of 160 MHz is required for a spreading factor of 32. In third-generation (3G) mobile systems for high-data-rate links, the spreading factor drops to 4 in order to keep the bandwidth at 4 MHz. Such a low spreading factor makes CDMA almost look like TDMA. Other practical approaches include multicode CDMA modulation.

TDD vs. FDD — The BWA industry is currently debating the merits of time-division duplexing (TDD) vs. frequency division duplexing (FDD) in point-to-multipoint networks. FDD is the legacy used in the fixed wireless industry in point-to-point links originally established for transporting analog voice traffic, which is largely symmetric and predictable. TDD, on the other hand, is being used in the design of point-to-multipoint networks to transport digital data, which is asymmetric and unpredictable. While TDD requires a single channel for full duplex communications, FDD systems require a paired channel for communication, one for the downlink (hub to remote) and one for the uplink (remote to hub). In TDD transmit/receive separation occurs in the time domain, as opposed to FDD, where it occurs in the frequency domain. While FDD can handle traffic that has relatively constant bandwidth requirements in both communications directions, TDD better handles varying uplink/downlink traffic asymmetry by allocating time spent on up- and downlinks. Given that Internet traffic is bursty (i.e., time-varying), the uplink and downlink bandwidth needs vary with time, which favors TDD. TDD requires a guard time equal to the round-trip propagation delay between hub and remote units. This guard time increases with link distance. Timing advance can be employed to reduce the required guard time. In FDD sufficient isolation in frequency between the uplink and downlink channels is required. Summarizing, FDD seems to be the simpler to implement but less efficient solution.

The MAC Layer and RLP

The MAC layer and RLP work with the physical (PHY) layer to deliver the best possible QoS in terms of throughput, delay, and delay jitter to the aggregate of users. The major task of the MAC layer is to associate the transport and QoS requirements with the different applications and services, and appropriately prioritize and schedule transmission over up- and downlink. A wireless MAC protocol should therefore provide differentiated grades and quality of service, dynamic bandwidth allocation, and scheduling for bursty data. An important feature of the MAC layer is the ability to perform retransmission, which allows operation at higher error rates and hence better frequency reuse, increases robustness, and improves TCP performance. The major MAC functions are:

- Controlling up- and downlink *transmission scheduling*, which allows support of multiple service flows (i.e., distinct QoS) on each CPE-BTS link.
- *Admission control* to ensure that adequate channel capacity is available to accommodate the QoS requirements of the new flow, and to enforce policy constraints like verifying that a CPE is authorized to receive the QoS requested for a service flow.
- *Link initialization* and maintenance like channel choice, synchronization, registration, and various security issues.
- *Support for integrated voice/data transport.* Typical data requirements are bandwidth on demand, very low packet error rates, and type-of-service differentiation. Voice requirements are bandwidth guarantees, and bounded loss, delay, and jitter.
- Support for *fragmentation*, *automatic repeat request* (ARQ), and *adaptive modulation and coding*.

We shall next summarize some MAC features, which are specifically desirable in the wireless case:

- *Fragmentation* of packet data units (PDUs) into smaller packets. This helps to reduce the packet error rate and limit the latency for voice.
- *Retransmission* on the level of fragmented PDUs.
- *Scheduling support* for multiple modulation/coding schemes.
- Wireless-specific *link maintenance and control* like uplink power control and adaptive modulation and coding.

Multiple Antennas in BWA

As outlined previously, fixed BWA systems face two key challenges: to provide high-data-rate and high-quality wireless access over fading channels at almost wireline quality.

The high requirement for quality arises because wireless BWA systems compete with cable modems and asynchronous DSL (ADSL), which operate over fixed channels and hence provide very good quality. This high quality requirement constitutes a major difference from existing mobile cellular networks, where customers are used to accepting low QoS. Also, in existing mobile cellular networks the requirements for data rate are much lower than in the fixed BWA case. The use of multiple antennas at the transmit and receive sides of a wireless link in combination with signal

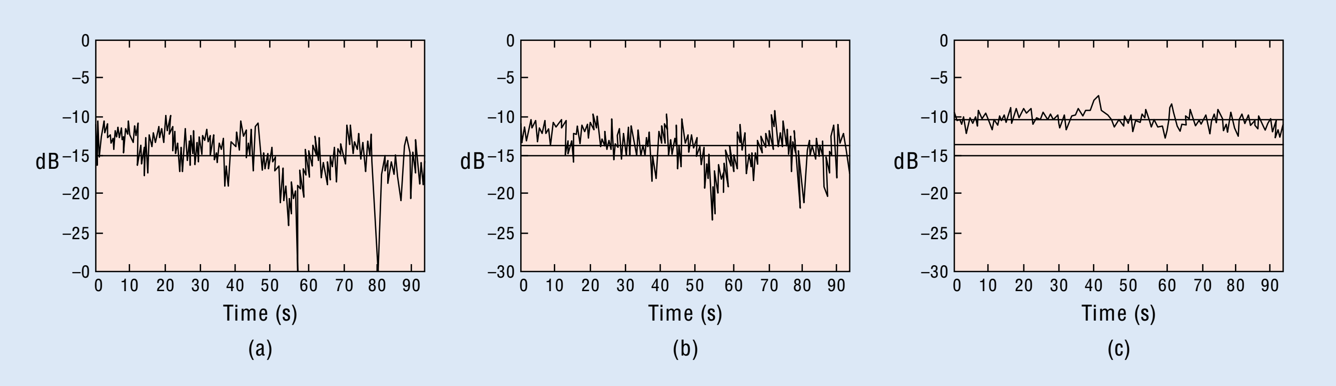

Figure 3. *Signal level at the receiver of: a) a 1-input 1-output; b) a 1-input 2-output; and c) a 2-input 3-output system.*

processing and coding is a promising means to meet all these requirements. Note that in fixed BWA as opposed to mobile cellular communications, the use of multiple antennas at the CPE is possible.

The leverages provided by the use of multiple antennas at both the BTS and CPE are as follows:

- *Array gain*: Multiple antennas can coherently combine signals to increase the C/N value and hence improve coverage. Coherent combining can be employed at both the transmitter and receiver, and requires channel knowledge. Since channel knowledge is hard to obtain in the transmitter, array gain is more likely to be available in the receiver.
- *Diversity gain*: Spatial diversity through multiple antennas can be used to combat fading and significantly improve link reliability. Diversity gain can be obtained at both the transmitter and receiver. The recently developed space-time codes [5] realize transmit diversity gain without knowing the channel in the transmitter.
- *Interference suppression*: Multiple antennas can be used to suppress CCI and hence increase cellular capacity.
- *Multiplexing gain*: The use of multiple antennas at both the transmitter and receiver allows opening up parallel spatial data pipes within the same bandwidth, which leads to a linear (in the number of antennas) increase in data rate [6–8].

Summarizing, the use of multiple antennas at both the BTS and CPE can improve cellular capacity and link reliability. More details on the impact of multiple antennas on cellular networks can be found in [9]. The recent developments of space-time coding [5] and spatial multiplexing [6–8] will next be discussed in more detail.

SPACE-TIME CODING AND TRANSMIT DIVERSITY

Two of the major impairments of wireless communications systems are fading caused by destructive addition of multipaths in the propagation medium and interference from other users. Diversity provides the receiver with several (ideally independent) replicas of the transmitted signal and is therefore a powerful means to combat fading and interference. Common forms of diversity are time diversity (due to Doppler spread) and frequency diversity (due to delay spread). In recent years the use of spatial (or antenna) diversity has become increasingly popular. Receive diversity (i.e., the use of multiple antennas on the receive side) is a well-studied subject [10]. Driven mostly by mobile wireless applications, where it is difficult to deploy multiple antennas in the handset, the use of multiple antennas on the transmit side in combination with space-time coding (transmit diversity) has become an active area of research. Space-time coding (transmit diversity) is a method which yields diversity gain without channel knowledge in the transmitter by coding across antennas (space) and across time. To demonstrate the impact of diversity gain on the performance of a BWA system, Fig. 3 shows the signal level at the receiver of a BWA system with and without antenna diversity. We can clearly see that the deep fades in the single-antenna case vanish in the multiple-antenna case. Hence, diversity renders the channel less fading, which is of fundamental importance in fixed BWA systems where deep fades can occur and the channel is changing slowly, causing the fades to persist over a long period of time. Figure 4 shows the signal and interference levels for a single-antenna system and a multi-antenna system, respectively. We can see that in the multi-antenna case the signal level is higher and fluctuates much less. Hence, more aggressive frequency reuse is possible in the multi-antenna case, which improves cellular capacity. We note that in the fixed BWA case it is difficult to exploit time diversity since the channel is changing slowly and interleaving over long periods of time would be necessary, which is not consistent with stringent delay requirements. ARQ allows us to realize some time diversity. Frequency diversity is likely to be available in the fixed BWA case, but is not a reliable source of diversity since large delay spreads cannot always be guaranteed [2, 3], especially when directional antennas are used where the amount of delay spread is significantly reduced. Measurements conducted by the Smart Antennas Research Group at Stanford University have shown that in a macrocell MMDS environment, half-wavelength antenna spacing suffices to ensure high spatial diversity gain. Therefore, spatial diversity is a very reliable form of diversity.

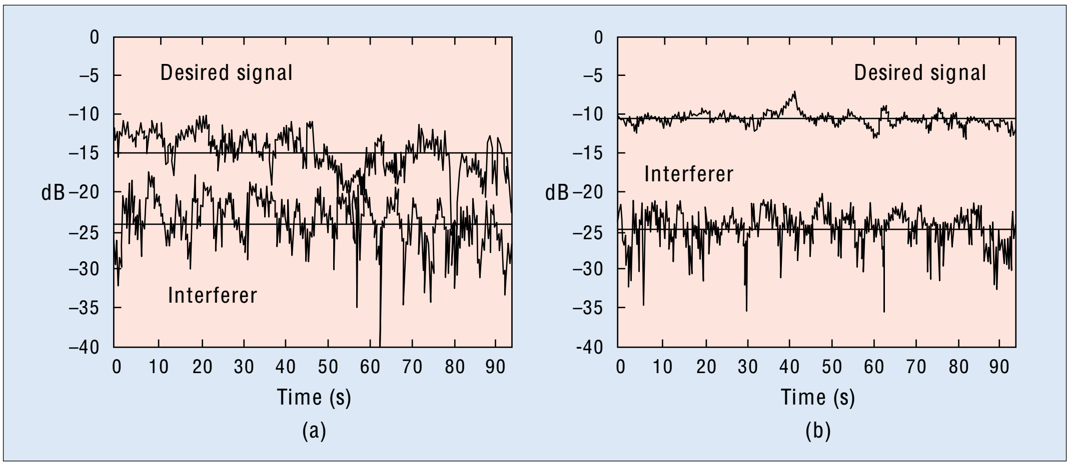

Figure 4. *Signal and interference levels for an: a) 1-input 1-output; and b) 2-input 3-output system.*

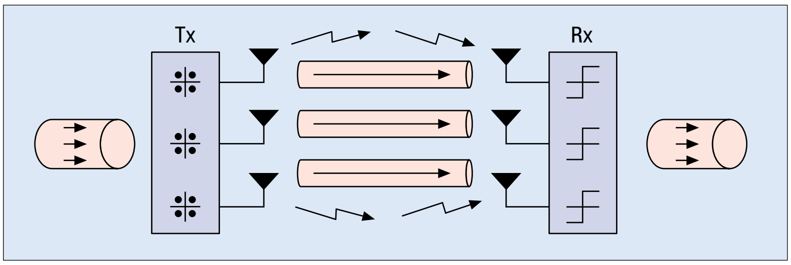

Figure 5. *A schematic of a spatial multiplexing system.*

SPATIAL MULTIPLEXING

Spatial multiplexing is a technique that yields an increased bit rate by using multiple antennas at both ends of the wireless link [6–8]. This increase comes at no extra bandwidth or power consumption. The basic idea is that the use of multiple antennas at both the transmitter and receiver opens up multiple parallel spatial data pipes within the same bandwidth and allows linear (in the number of antennas) capacity increase provided rich enough scattering is present. The use of spatial multiplexing thus seems particularly interesting in the case of fixed BWA, where a very high data rate is required. Figure 5 shows the schematic of a spatial multiplexing system. Since multiplexing gain is obtained only if the scattering environment is rich enough or, equivalently, sufficient multipath and delay spread is present, spatial multiplexing will work better with omnidirectional antennas since directional antennas tend to limit the multipath contribution and reduce the delay spread.

FUTURE CHALLENGES AND INDUSTRY TRENDS

In this section we briefly describe some future challenges of fixed BWA, provide an overview of some of the existing standards for BWA, and discuss some recent industry trends.

FUTURE CHALLENGES

We outlined above that in fixed BWA, even though the transmitter and receiver are located at fixed points, the low BTS and CPE antenna heights, and the influence of wind, motion of traffic, and foliage make for a very hostile fading environment. Temporal fades of over 30 dB at the rate of at most 1–2 Hz are frequently seen in the band below 3 GHz. Since fixed BWA basically competes with cable modems and ADSL where the channel is static and nonfading, very high demands on quality are imposed besides the significantly higher demands on data rate. The major challenge is therefore to engineer a wireless link in a fading environment to look like a wireline link. One possible solution is to use multiple antennas, as discussed in the previous section. Recent industry activities suggest that the use of multiple antennas in combination with OFDM (MIMO-OFDM) is particularly promising for fixed BWA. The second major challenge is at the MAC layer, where it is crucial that future MACs support sophisticated physical layer techniques such as adaptive modulation and coding, space-time coding, and spatial multiplexing.

STANDARDS

Broadband radio access standards and architectures are currently under serious discussion in Europe, Japan, and the United States. Different regions and countries use different terms when referring to these standards. In Europe, they are referred to as Broadband Radio Access Networks (BRAN); in the United States, as Local Multipoint Distribution Service (LMDS), IEEE 802.16, and Broadband Wireless Access (BWA) systems, among other terms. In Canada and some other countries, they are also referred to as Local Multipoint Communication Systems (LMCS). Their applications, however, are varied: fixed and mobile, local and wide area, and include promising applications such as:

- High-speed Internet access
- Two-way data communications (peer–peer or client/server)
- Private or public telephony
- Two-way multimedia services such as videoconferencing and video commerce
- Broadcast video

Broadband access consists of what is termed as High-Performance Radio Access (HIPERAC-

CESS), HIPERLAN, and HIPERLINK, as shown in Fig. 6. While the ETSI definitions indicate a distinct hierarchical topology, it is possible that wireless LANs directly connect to either the backbone or the HIPERACCESS terminals.

HIPERACCESS systems connect mainly residential, small office/home office (SOHO), and small to medium enterprise (SME) premises to gain access to a variety of telecommunications services such as voice, data, and multimedia services with transmission rates varying from about 2 Mb/s to 25 Mb/s. HIPERACCESS will primarily be used as a broadband remote access network. The radio spectrum can be in the 2–40 GHz range.

The second application referred to above, HIPERLAN, provides local access with controlled QoS for broadband applications (e.g., Internet and videoconference) to portable computers for use within buildings and on campus using mainly unlicensed radio spectrum in the 5 GHz band.

The third application of BRAN is called HIPERLINK, and is primarily a network–network radio interconnection which will support a variety of protocols and all the above traffic scenarios. This application would use bit rates of up to 155 Mb/s in parts of the 17 GHz radio spectrum.

IEEE802.16 covers more issues than HIPERACCESS, including WirelessMAN and Wireless High-Speed Unlicensed Metropolitan Area Networks (HUMAN), which include the frequencies from 2 up to 66 GHz. Previously IEEE 802.16 MAC and PHY had two options: DOCSIS-based and non-DOCSIS-based. Currently the committee is working toward merged solutions to reflect the emerging wireless Internet applications and coexistence with other wireless access technologies. For details, see http://www.ieee802.org/16.

The International Telecommunication Union (ITU) initiated a working group called ITU JRG 8A-9B in charge of broadband wireless access system standardization issues. This group receives input from BRAN and IEEE802.16 and tries to deliver a global consensus on this technology from the standpoint and function of the ITU. For details, please see http://www.itu.int/was.

FUTURE TRENDS

Important future trends of BWA will be:

- Evolving BWA from mostly business applications to residential applications
- Bandwidth on demand and high spectrum utilization becoming a key issue
- More reconfigurable systems and adaptivity to support multiband, multiple standards, and multiple carriers
- Convergence of broadband wireless access and broadband wireless mobile [11]

With the new spectrum allocated by the ITU for future fourth-generation mobile communications (4Gmobile), convergence of BWA and 4Gmobile will be a major focus of activity in wireless communications.

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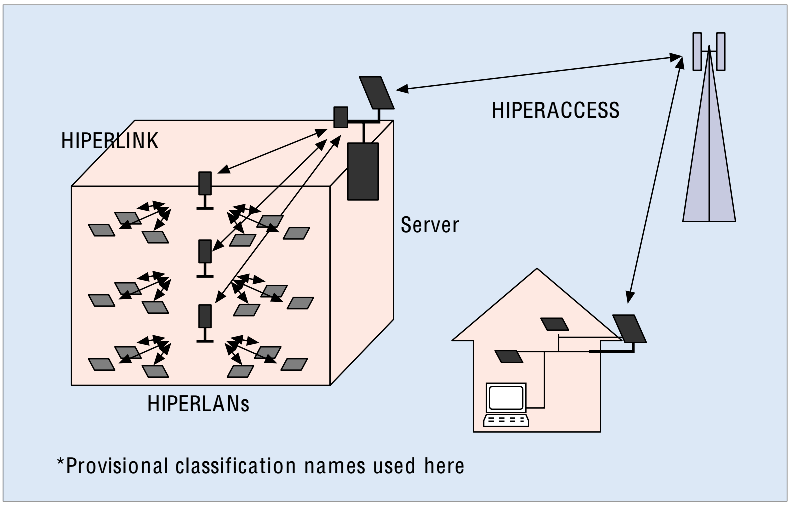

Figure 6. *Broadband wireless access (source: Nortel Networks).*

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