Comparative Evaluation of UMTS, WLAN, BWA, MBWA and UWB Systems

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Abstract. *UMTS, WLAN, BWA and UWB systems are compared in this paper. The comparative analysis covers system capacity, QoS, and radiowave propagation.*

Keywords

UMTS, WLAN, BWA, UWB, IEEE 802.11, IEEE 802.16, capacity, QoS, propagation.

1. Introduction

The purpose of this paper is to make the categorization of modern mobile communication systems with respect to their key features and technological design aspects. Suitability of a particular system for a given service type is reviewed based on the specific physical environment, system characteristics, available capacity and system cost. The systems considered in this paper include: UMTS representing 3G mobile communication networks, WLAN based on standards IEEE 802.11, IEEE 802.16 BWA system, and UWB as a future player in the field. UMTS is described at the beginning in detail, since all possible services and various techniques, which are parts of other technologies under study as well, are available in UMTS.

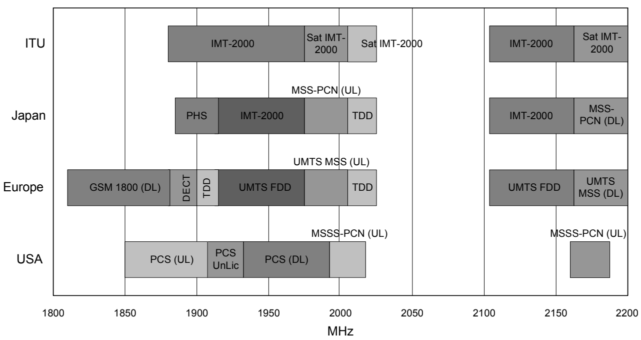

Fig. 1. Worldwide available frequency spectrum

2. UMTS

The object of UMTS (*Universal Mobile Telecommunication Systems*) is to provide wide range of services in both, circuit switched (CS) and packet switched (PS) domain to a mobile customer [1]. Services of interest include voice, real-time multimedia services, WWW browsing, data download, etc. Reference data rates with respect to the physical environment and user mobility were defined within 3GPP and are summarized in Tab. 1. Such a wide variety of services to be offered led to a definition of a new air interface standard.

New frequency spectrum was allocated by ITU for UMTS networks. In Europe the available frequency band has been divided into a two parts: 'paired' and 'unpaired'. The 'paired' has a bandwidth of 2x60 MHz (60 MHz for uplink 60 MHz for downlink). The 'unpaired' part has a bandwidth of 35 MHz (20 + 15 MHz) and it is not determined in advance if the particular band is for uplink or downlink. For more detailed allocation of the frequency bands available in the rest of the world see Fig. 1.

Environment	Max bit rate [kbps]	Max. speed [km/h]	Cell type
Rural outdoor	144	500	Macrocell
Suburban outdoor	384	120	Macrocell Microcell
Indoor/Low range outdoor	2048	10	Picocell Microcell

Tab. 1. UMTS reference data rate & user mobility

Compared to already traditional TDMA air interface access scheme of second-generation mobile networks, the air interface for UMTS is based on a *Wideband Code Division Multiple Access* (W-CDMA). Moreover both TDD and FDD modes were specified to co-exist seamlessly in UMTS to meet performance requirements. UMTS FDD mode will be considered in further readings of this paper.

2.1 Service Differentiation & QoS

UMTS services were divided into four classes according to services characteristics [2]:

- *Conversational*
- *Streaming*
- *Interactive*
- *Background*

Services within *conversational* class are characterized by preservation of time relation between information entities.

Additionally there is a strong requirement for low delay. Services in this class are commonly real time services like voice, video-telephony, real time games, etc. *Streaming* class of services is characteristic with preserving time relations between information entities, but with more relaxed requirement to transport delay. Services included in this class are all types of streaming multimedia. Services belonging to the *interactive* class are based on a request response principle. Well-known example of the service within this class is a web browsing or non-real time network games. *Background* service class associates services, where the recipient of information is not expecting the data in a given time. The service only guarantees the data integrity. Email background downloading is a typical example of such service class.

The UMTS service architecture is shown on Fig. 2 [1]. Because of layered service architecture in UMTS the user can negotiate and re-negotiate or change the bearer characteristics based on the QoS demand, network resource availability, and application needs.

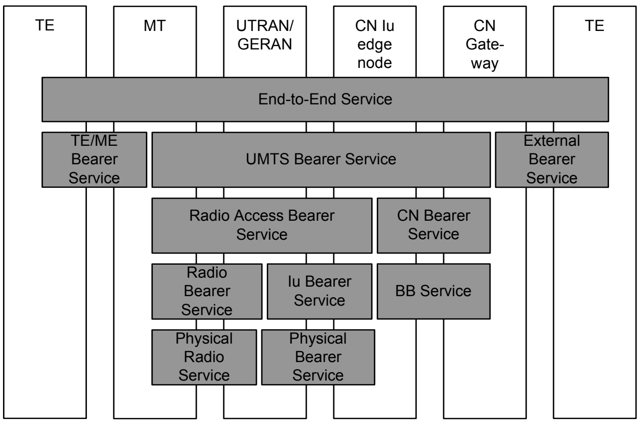

Fig. 2. UMTS service architecture

In order to enable enhanced traffic differentiation, more QoS attributes has been defined along the service class. The attributes are negotiated during connection setup procedure (PDP context activation procedure for packet switched part of UMTS bearer service). The set of QoS attributes defines QoS profile and defines: traffic class, target transfer delay, reliability, priority, etc. Summary of UMTS bearer service attributes defined in [3] is given in Tab. 2.

2.2 System Performance, Physical Environment and Service Availability

In order to review the services available in UMTS with respect to the physical environment we should first give a short overview of the air interface standard for UMTS.

W-CDMA for UMTS is based on a *Direct Sequence Spread Spectrum* (DSSS). In this case the available radio resource is shared between users by allocating unique sequence to each user willing to transport the information. Thus each user utilizes the whole bandwidth of the channel up to time the user stops the information exchange. It is completely different from the other multiple access techniques (e.g. TDMA or FDMA), where available radio resources are divided into a certain number of 'sub-channels' in a time or frequency domain for TDMA and FDMA respectively. In DSSS the user data is multiplied by a unique sequence called spreading sequence, which has the bit (commonly it is called 'chip') duration much less then user data bit duration (spreading operation). In the receiver the information is multiplied with the same spreading sequence again, thus obtaining the original narrowband signal back. This process is called despreading. One of the very important properties of CDMA systems is a tolerance to narrowband interference. The amount of interference possibly suppressed is dependant on the available processing gain

$$G_p = R_c / R_i \quad , \tag{1}$$

R_c is a chip rate and R_i is the information data rate. Other words the processing gain can be seen as an improvement factor in the signal to interference ratio of the signal after the despreading [1]. In W-CDMA the R_c is 3.84 Mcps, with basic channel raster 5 MHz. The drawback of CDMA systems is a near-far problem, resulting in the need for accurate fast power control (PC), and very tight requirements on synchronization. For detailed information on CDMA the reader is referred to [4], [5], [6].

Traffic Class	Conversational	Streaming	Interactive	Background
Max. bitrate	x	x	x	x
Delivery order	x	x	x	x
Max. SDU size	x	x	x	x
SDU format information	x	x		
SDU error ratio	x	x	x	x
Residual BER	x	x	x	x
Delivery of erroneous SDUs	x	x	x	x
Transfer delay	x	x		
Guaranteed bit rate	x	x		
Traffic handling priority			x	
Allocation/Retention priority	x	x	x	x

Tab. 2. UMTS bearer attributes for each traffic class

Because there will co-exist many users with different services requiring different bit rates in a single cell, the *Orthogonal Variable Spreading Factor* (OVSF) code was introduced in W-CDMA. The term spreading factor (SF) often used in 3GPP specifications expresses the number of chips of the spreading sequence representing one bit of information (user data plus additional bits due to overhead, error control coding, etc.). It is constructed based on the Hadamard matrix with the property that the two different codes from one family are orthogonal to each other when they are in phase. The code tree is shown on Fig. 3.

For downlink the spreading sequence separates different connections to different users served by the cell. For uplink the spreading sequence separates different channels from one terminal. The separation between different cells on downlink and between different users in uplink is guaranteed by the scrambling operation. From previous it is clear that the number of available codes could be a limiting factor only in the downlink. In the case that there is not enough codes at the Node B (note that the Node B is a term used within 3GPP for a radio base station) for downlink within single code tree, the second scrambling code might be used, thus obtaining additional code tree. The problem is that these two sets of codes are not orthogonal to each other any more and causes more interference. See [2] for details.

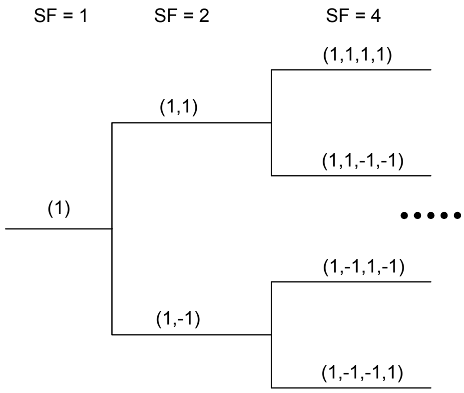

Fig. 3. OVSF code tree generation

In downlink the QPSK modulation is used due to time multiplexing of data and control channel. Dual channel QPSK modulation is used in uplink, which is a result of I/Q-multiplexing of data and control channel. Different modulation is used on *uplink* (UL) in order to avoid an audible disturbance to audio equipment, which is close to the terminal. The resultant symbol rates and examples of services for UL and *downlink* (DL) are given in Tab. 3 and 4 [1].

SF	Channel symbol rate [kbps]	User bit rate [kbps]	Services
256	15	3.4	Stand-alone control channel
128	30	-	-
64	60	12.2 + 3.4	Speech + control channel
32	120	28.8 + 3.4	Modem + control channel
16	240	57.6 + 3.4	Fax + control channel
8	480	12.2 + 144 + 3.4	Speech + packet data + control channel
4	960	12.2 + 384 + 3.4	Speech + packet data + control channel

Tab. 3. Channel symbol rates and example of services (UL)

One can see that the maximum data rate per one channel is 960 kbps (uncoded). Realistic data rate would be 480 kbps when coding with coding rate 1/2 is applied. For higher data rate multicode transmition is defined within specifications, allowing up to 6 parallel channels yielding to 2 Mbps even after retransmissions. Note that regardless of the user bit rate (12.2 kbps, 64 kbps, 144 kbps, 384 kbps, or even 2048 kbps) occupied channel bandwidth is approx. 5 MHz.

SF	Channel symbol rate [kbps]	User bit rate [kbps]	Services
512	7.5	-	-
256	15	3.4	Stand-alone control channel
128	30	12.2 + 3.4	Speech + control channel
64	60	28.8 + 3.4	Modem + control channel
32	120	57.6 + 3.4	Fax + control channel
16	240	12.2 + 144 + 3.4	Speech + packet data + control channel
8	480	12.2 + 384 + 3.4	Speech + packet data + control channel
4	960	-	-

Tab. 4. Channel symbol rates and example of services (DL)

In UMTS the user distance from serving base station becomes a critical issue from the service availability point of view. This is due to the fact that the network can offer different processing gain to different services. Recall the formula (1) where the amount of processing gain is directly proportional to required bit-rate. It means that the system might have very good availability for voice users at the cell edge, but for data users requiring high bit-rates the service is simply not available in the same location. The evaluation of proper mutual distance among base stations is a task for a power budget calculation during the network dimensioning process. The power budget calculation should be performed separately for each service providing coverage in the whole area. From result the most critical service must be identified (i.e. the service with minimal allowed path loss). From path loss the corresponding distance can be obtained. Note that in the power budget not only the path loss calculation is involved, but more or less the radio wave propagation in general.

The dynamic changes of surrounding obstacles (e.g. cars) and user speed causes that the instantaneous received signal fluctuates (this is often called signal fading). The depth and statistical characteristics of signal fading depends on actual radio environment characteristics. For NLOS case the depth of signal fade might reach up to 35-40 dB and statistical distribution is close to Rayleigh. Whereas in the case of LOS the signal fading is not so deep and reaches 15-20 dB and statistical distribution is close to Rician. For signal fading mitigation, diversity techniques are often used at the Node B. The diversity gain should be subsequently used in power budget calculation. Additional gains or losses that should be taken into account in the power budget are indoor or incar losses, vegetation attenuation etc., dependant on current subscriber location. Also note that radio wave propagation in such a frequency band is not affected by rain as it is in the high frequency band. Path loss calculation for macrocells (e.g. diameter of 1 – 10 km) is commonly resolved by some of commonly accepted empirical propagation models (e.g. Okumura-Hata, Lee, Parsons, etc.), which are easy to use and provides with results of acceptable accuracy for power budget. These models do not deal with reflections, diffractions, etc. For microcells (e.g. 0.1 – 1 km) different propagation models are commonly used. In this type of environment the reflections and diffractions are inevitable part of radio wave propagation. Also NLOS and LOS situation should be reflected. For picocels (cell covering building or only part of the building) the situation is even more complicated, since there are significant reflections from ceiling, walls etc. For detailed radio network planning more advanced and accurate propagation models should be used. These models often utilize some form of ray-launching or ray-tracing techniques, which require computerized calculation as well as the detailed digital map of desired area.

Such results from power budget calculation with typical Node B configurations for typical set of services can be seen in Tab. 5. One may identify that that for 384 kbps service it would be necessary to have 2.25 % more Node Bs compared to only 144 kbps. Note that in the later case the 384 kbps will be also available, but only in the limited area around the Node B. So the trade off between service availability and system cost must be found.

Service	12.2 voice	144 kbps data	384 kbps data
Allowed propagation loss [dB]	141.9	135.7	129.9
Cell radius [km]	2.3	1.5	1.0

Tab. 5. Allowed path losses and corresponding cell radius

Remember that the physical environment affects not only the path loss calculation and a network dimensioning process. The physical environment affects also requirements for signal processing, which are essential for capacity estimation. Base-band parameter E_b/N_0 is probably one of the most important. E_b/N_0 expresses the ratio of energy per bit and noise power density. The physical environment influences the radio channel characteristics (e.g. channel impulse response). Subsequently the radio channel characteristics imply the E_b/N_0 requirement. The higher is the E_b/N_0 requirement, the lower is the capacity of the system and less number of users might be served.

Moreover the E_b/N_0 requirement is dependant upon the service in use. Commonly in UMTS the E_b/N_0 value decreases with increasing bit-rate. This is mainly due to more power available for channel estimation in the case of high bit-rate services.

2.3 Services & System Capacity

It is commonly accepted fact that UMTS is a capacity limited system, meaning that new users can access the network until the amount of power received by the serving Node B from that users reaches some predefined threshold. The threshold is called 'noise raise' and expresses the ratio of a total wideband power received by Node B and noise.

Because the packet switched services with high bit rates can utilize only small processing gain, more power has to be transmitted in order to reach the E_b/N_0 requirement at the receiver. On the contrary compared to the voice services where there is no need to transmit that high power because of high processing gain available. It means that the higher is the transmitted power the lower is the number of users connected to the network before reaching the noise rise threshold. On the Fig. 5 the noise rise as a function of the number of 12.2 kbps voice respectively 144 kbps data users is shown.

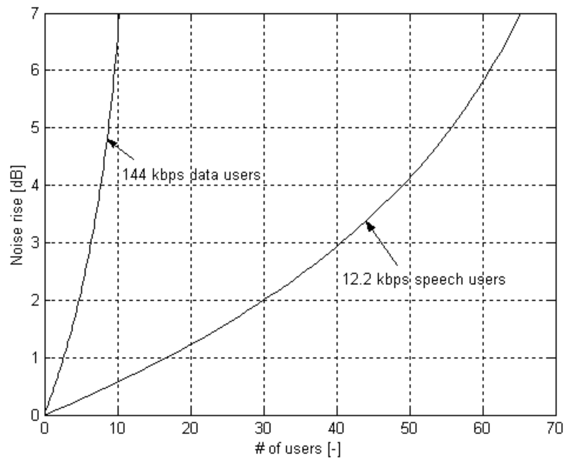

Fig. 4. Noise rise as a function of the number of users

Since there is a different requirement of E_b/N_0 value for services with different bit rate, the total throughput tends to increase when high data rate users are connected to the network and the noise rise reaches its limit at the Node B. This is due to lower requirement of minimal E_b/N_0 for high-speed data users. In other words there is not a direct rule of proportion between throughput and user bit rate.

2.4 Summary

From previous discussion we may conclude that UMTS is mobile cellular communication system, which can offer voice, CS and PS data services irrespective of user location and speed, commonly in a very large area. The maximum data rate per one user is limited to approximately 2 Mbps, with further limitation to the speed and location of such a user. More, we have shown that commonly UMTS can offer high data rate services only to a limited number of users. The higher is the user data rate the less users can access the system. Moreover it has been shown that the cell throughput increases with data rate of particular users. Implementation and maintenance costs of UMTS system is very high compared to systems given below.

3. WLAN Based on IEEE 802.11

Wireless LAN (WLAN) solutions appeared in the late of 1980s in order to compete with traditional wired LAN networks. The idea was to use the WLAN instead of traditional LAN in order to avoid necessary cabling in the service area and to obtain more flexibility for possible future changes in the network structure. The object is to provide a customer with wireless connection to it's LAN network. The 802.11 WLAN standard has been developed by IEEE P802.11 committee specifying PHY and MAC layer of a LAN wireless technology. For a public short range networks (hot spots) the 802.11b became the most popular standard.

In 1997 IEEE adopted IEEE 802.11 standard as a WLAN standard [7]. The main variants of 802.11 includes:

- *802.11a*
- *802.11b*
- *802.11g*

Note that other variants were defined as well, but will not be considered in this paper. Operating frequency band of considered 802.11 standards is given in Tab. 6.

Standard	Frequency band
802.11a	5 GHz
802.11b	2.4 GHz
802.11g	2.4 GHz

Tab. 6. Operating frequency bands for selected WLAN standards

IEEE 802.11a systems use OFDM as transmission technique and supports data rates from 6 to 54 Mbps. It utilizes BPSK, QPSK, and QAM to achieve the various data rates. The supported data rate and corresponding modulation type is given in detail in Tab. 7. OFDM is based on a *Fast Fourier Transform* (FFT). IEEE 802.11a OFDM enables overlapping of 52 channels without loosing their orthogonality, leading to better spectral utilization. Note that only 48 out of 52 subchannels carries data and the remaining 4 are used as a pilot tones used in phase tracking for coherent demodulation. By dividing the channel into a narrowband flat fading subchannels, the OFDM is more resistant against selective fading.

IEEE 802.11b uses DSSS as a transmission technique. Supported bit rates are 1, 2, 5.5 and 11 Mbps. The available frequency band is divided into a fourteen 22 MHz channels. 11 adjacent channels partially overlap and only 3 remaining channel do not. This is why only three IEEE 802.11b DSSS systems can be co-located. For 1 and 2 Mbps data rate operation BPSK and QPSK modulation technique is used respectively. In order to provide higher data rate to the customer IEEE 802.11b adds *Complementary Code Keying* (CCK) and *Packet Binary Convolutional Coding* (PBCC), which provide data rates up to 11 Mbps. Note that regardless of whether the data rate is 1, 2, 5.5, or 11 Mbps, the channel bandwidth is about 20 MHz for DSSS systems.

IEEE 802.11g introduces OFDM to a 2.4 GHz frequency band in order to provide higher data rates (at least 20 Mbps), while maintaining backward compatibility with existing systems based on 802.11b. Supported data rates are up to 54 Mbps. In case the hybrid CCK/OFDM is used the maximum supported bit rate is 54 Mbps and in case of PBCC the maximum supported bit rate is 33 Mbps. CCK and OFDM are mandatory in specification whereas CCK/OFDM and PBCC are optional.

Data Rate [Mbps]	Modulation
6	BPSK
9	BPSK
12	QPSK
18	QPSK
24	16QAM
36	16QAM
48	64QAM
54	64QAM

Tab. 7. Supported data rate and corresponding modulation type

3.1 Service Differentiation & QoS

In general the 802.11 does not offer adequate QoS in terms of delay requirements and service prioritization, which is necessary for voice and real-time data services. In order to provide at least a limited QoS two modes of operation has been specified for the MAC layer: the *Distributed Coordination Function* (DCF) and the *Point Coordination Function* (PCF).

DCF is the basic 802.11 MAC and most of the commercial systems operate in this mode. DCF is based on *Carrier Sense Multiple Access with Collision Avoidance* (CSMA/CA). CSMA/CA is very similar to Ethernet's *Carrier Sense Multiple Access with Collision Detection* (CSMA/CD); however, due to the implementation of the wireless transceiver, collision detection is not possible. In this mode nothing is guaranteed in terms of the QoS. The PCF mode of the MAC layer provides the limited QoS in terms of provisioning of priority access to the medium by polling the stations in a round-robin fashion [7]. Note that any station can request to be added to the poll sequence by a special frame exchange sequence. Voice services could be provided within this mode.

In order to enable the transport of voice over IP (VoIP) and real-time data services the IEEE 802.11e has been introduced. The 802.11e specification introduces two new modes of MAC layer operation: *Enhanced DCF* (EDCF) and the *Hybrid Coordination Function* (HCF). As with the original 802.11 MAC, the 802.11e enhancements are designed to work with all possible 802.11 physical layers (the original 802.11, the current 802.11, 802.11a, and 802.11g).

3.2 System Performance, Physical Environment and Service Availability

Generally the influence of the transmitter and the receiver separation on a system performance is very similar to UMTS system as was described in previous sections. Additionally there is significant limitation in a maximum allowed transmitting power (1000mW in North America and 100mW in Europe). In Tabs. 8 and 9 we provide the overview of approximate reliable ranges for IEEE 802.11b and IEEE 802.11a for different types of physical environments. Note that overall throughput of the system decreeases with number of users connected to the access point.

Data rate	Reliable range [m]		
	Open plane building	Semi-open office	Closed office
1 Mbps	490	100	45
2 Mbps	350	85	40
5.5 Mbps	260	70	35
11 Mbps	190	55	30

Tab. 8. Reliable distances for IEEE 802.11b with respect to offered bit rate

Concerning radiowave propagation in case of WLAN 802.11 systems, it is very similar to principles already mentioned in the previous section dealing with UMTS. Particularly the environment is of a picocell type. The signal fading of Rayleigh or Rician statistical distribution also occurs due to the possible movement of the subscriber and the movement of surrounding objects (e.g. people). Diversity techniques are often used to mitigate the signal fading at the subscriber as well as at the access point site (space diversity). Special attention must be given to a strong reflection from walls, ceiling and floors, often creating the waveguide effect. Building configuration as well as the materials used in the building should be known prior to the radio network planning in order to accurately optimize the propagation models. At present mostly the PC tools dedicated only for that purpose are used to provide accurate radiowave propagation model.

Data rate	Reliable range [m]
	Open plane building
6 Mbps	70
12 Mbps	55
⋮	⋮
48 Mbps	14
54 Mbps	7

Tab. 9. Reliable distances for IEEE 802.11a with respect to offered bit rate

3.3 Summary

An overview of WLAN based on the IEEE 802.11 family standard has been given in this section. As a conclusion we may say that such a type of WLAN is most convenient for large buildings to compete with traditional LAN system. The coverage area is commonly much less (few hundreds of meters) then in the case of UMTS. Note that the small range of the system can be solved using IEEE 802.16 or others. The system provides its services in a PS domain only. QoS cannot be guaranteed for voice and realtime multimedia services in legacy IEEE 802.11 standard. Some improvements were introduced in IEEE 802.11e standard.

4. BWA Based on IEEE 802.16

Broadband Wireless Access (BWA) systems were designed to provide an alternative to the wired "last mile" access link. The BWA network is commonly composed of at least one base station (BS) and several subscriber stations (SS) (i.e. since the SSs are stationary the system is of point-to-multipoint type). IEEE 802.16 standard belongs to this category of access systems. Similarly as in the case of WLAN based on IEEE 802.11 family, there exist several variants of IEEE 802.16 system, with multiple PHY layers and common MAC layer. It was designed to provide multiple services with different QoS and priority requirements simultaneously. The system variances with respect to the frequency bands are given in Tab. 10.

Standard	Frequency band
802.16	10 - 66 GHz
802.16a	2 - 11 GHz
802.16b	5 - 6 GHz

Tab. 10. IEEE 802.16 variances

Common requirement for *IEEE 802.16* deployment in the service area is the existence of LOS between transmitter and the receiver. In IEEE 802.16, both TDD and FDD duplexing schemes are supported. Multiple access scheme on uplink direction is by time-division multiple access (TDMA). Modulation scheme used in the air interface is related to the instantaneous channel quality. QAM 64, QAM 16 and QPSK modulation schemes were defined. High bit rate is reached by utilization of broadband channels (20, 25 or 28 MHz). Channel bandwidth, related modulation schemes and the resultant bit rates are summarized in Tab. 11. In order to compensate link quality degradation between SS and BS, IEEE 802.16 utilizes a so-called "adaptive burst profile" in both uplink and downlink, meaning that the modulation type as well as the coding scheme is assigned burst-by-burst per subscriber station depending on the instantaneous channel conditions.

Channel bandwidth	Symbol rate [Msps]	Bit rate [kbps]		
		QPSK	16 QAM	64 QAM
20 MHz	16	32	64	96
25 MHz	20	40	80	120
28 MHz	22.4	44.8	89.6	134.4

Tab 11. Available bit rate with respect to modulation type

Design of *IEEE 802.16a* PHY layer is driven from the need of NLOS operation requirement. There are three air interface specifications given in the draft:

- *WirelessMAN-SC2*
- *WirelessMAN-OFDM*
- *WirelessMAN-OFDMA*

WirelessMAN-SC2 uses single carrier modulation format, WirelessMAN-OFDM uses orthogonal frequency-division modulation with 256-point transform, while WirelessMAN-OFDMA uses orthogonal frequency-division modulation with 2048-point transform.

4.1 Service Differentiation & QoS Mechanism

In order to guarantee the QoS targets each uplink connection is mapped to the *scheduling mechanism*. Certain amount of rules is associated with the scheduler, which is responsible for allocation of the uplink resources. Particular rule is defined during the connection setup time. Services generating periodically the data to be transferred (e.g. like an ATM constant bit rate service class) will use *unsolicited grant service* (UDS). Here the BS schedules regularly, in a preemptive manner, grants of the size negotiated at connection setup, without an explicit request from the SS. This eliminates the overhead and latency of bandwidth requests in order to meet the delay and delay jitter requirements of the underlying service [8]. For the VoIP or streaming services the *real-time polling service* (rtPS) is well suited. In this case the bandwidth-on-demand approach is applied. It means that the SS issues explicit requests, which increases the overhead and latency, but the capacity is granted based on demand. For the non-real time services tolerating higher latency and not-guaranteed bit rate (e.g. internet connection) the *non-real time polling service* (nrtPS) was defined. Moreover the *best effort* (BE) service has been defined as well. Here neither throughput nor the delay is guaranteed (i.e. for e-mail downloads, etc.).

4.2 System Performance, Physical Environment and Service Availability

From the radiowave propagation point of view the connection between terminal and base station is always provided in terms of LOS in IEEE 802.16 systems. Additional significant attenuation component must be considered for IEEE 802.16 systems: attenuation caused by rain. Attenuation due to rain was not considered in UMTS and WLAN based on IEEE 802.11 systems due to lower operating frequency (i.e. less than 5 GHz), compared to IEEE 802.16. Note that water vapour resonance occurs at 1.3 cm (23 GHz), thus the rain attenuation for the frequencies below 5 GHz is negligible [10]. Commonly it is accepted that rain attenuation below 10 GHz is insignificant compared to attenuation caused by refraction effects. Nevertheless for IEEE 802.16 the attenuation by tree must be considered. As the rain rate increases the amount of water between transmitter and receiver increases as well and causes significant attenuation. This fact yields to the attenuation due to rain be function of actual rain rate. Rain rates are provided by ITU in terms of different zones defined as rainfall rate, which is only exceeded for 0.01% of the time. Moreover the higher is the frequency band the higher is the water absorption.

Moreover for the frequencies well above 30 GHz, the attenuation due to rain as well as due to vegetation must be estimated with high accuracy since the available transmitting power is very limited. Even that the IEEE 802.16 is a connection with stationary transmitter and the receiver it is sometimes necessary to deal with "fast" signal fading. Signal fading in this case would occur when tree shadows the terminal antenna. Since the tree is loaded by the wind it is not stationary and the movement of leaves and branches causes multipath propagation implying signal fluctuation (note that depth of signal fades is often more that 20 dB). Especially for the real time services this phenomenon should be reflected during power budget calculation as well. In order to obtain required service availability any kind of diversity could overcome deep signal fading.

4.3 Summary

An overview of BWA based on the IEEE 802.16 family standard has been given in this section. As a conclusion we may say that BWA is most convenient for large cities to compete with traditional fixed line distribution systems. BWA based IEEE 802.16 is capable to provide any type of service due to different scheduling algorithms that were defined. The coverage area is relatively large compared to WLAN and UMTS. Attenuation due to rainfall must be considered as well as the signal fluctuation due to tree movement should be reflected.

5. MBWA Based on IEEE 802.20

IEEE 802.20 also called as *Mobile Broadband Wireless Access* (MBWA) is a system that should provide the subscriber with mobile and ubiquitous access to internet and/or intranet network. Since the system specifications are not available yet we will discuss the planned system characteristics only. MBWA solution characteristics are summarized in Tab. 12. Operating frequency is supposed to be in the license band below 3.5 GHz. Some of well-proven spread spectrum technique (e.g. frequency hopping, OFDM) should be used on the air interface to enable the frequency reuse = 1, thus avoiding frequency planning.

Characteristic	Channel bandwidth	
	1.25 MHz	5 MHz
Mobility [km/h]	up to 250	
Maximum data rate (DL)	< 1 Mbps	< 4 Mbps
Maximum data rate (UL)	< 300 Kbps	< 1.2 Mbps

Tab. 12 System characteristics

5.1 Service Differentiation & QoS Mechanism

The system shall provide subscribers with real-time as well as non-real time services while optimized to packet-data. Fast resources allocation for both UL and DL should be deployed. User data rate management should be resolved to support for the automatic selection of optimized user data rates that are consistent with the RF environment constraints.

5.2 System Performance, Physical Environment and Service Availability

From the radiowave propagation point of view, IEEE 802.20 reflects the same principles as mentioned previously in UMTS section.

6. UWB

The *ultra wide-band* (UWB) radio is a radio technology using very large bandwidth. The definition by FCC stands that term very large bandwidth is the bandwidth wider then 25% of a central frequency in use or alternatively the bandwidth wider then 1 GHz. UWB emission are targeted to be that small so it can co-exist with other narrowband systems without disturbing them. The current narrowband users would "see" very small if any increase of the background noise level. Note that generation of UWB signal might be different, in [9] two methods are mentioned: *time modulated* (TM-UWB) and *Direct Sequence Phase Coded* (DSC-UWB).

6.1 TM-UWB Technology

In TM-UWB transmitter emits ultra-short monocycle wavelets with tightly controlled pulse-to-pulse intervals. In other words, to convey the information, pulse position modulation is used. When the data symbol to be transmitted is 1, a small time shift is added to the monocycle. Note that one data symbol spans many monocycles. When the data symbol is 0, there is no time shift added to the monocycles. When multiple simultaneous users are desired to access the same bandwidth, each user has distinct periodic pulse shift pattern derived from PN sequence. Note that TM-UWB has many commonalities with CDMA principle. For example, large processing gain, excellent multipath immunity, and narrowband interference immunity. At high frequencies the (over 2 GHz) available bit rate might reach 60 Mbps in the indoor environment within the range of 50 m. In lower frequency bands bit rate is not likely to exceed 100 kbps.

In the lower frequency band (below 2 GHz) it is likely that the system will be used in different areas then communication. Due to the properties like excellent multipath immunity the system is ideal for service categories like medical or automotive. The positioning applications are the most interesting due to the high accuracy of the position estimation.

The UWB technology will not be covered in the comparative analysis since it would commonly serve for very special applications.

7. Comparative Analysis

In the previous sections we have given the short overview of the system parameters and characteristics that we found to be important for a rough comparison analysis of the systems from the QoS provisioning, system planning and availability point of view. We focused on UMTS, WLAN, BWA and UWB systems. The overview of characteristics is given in Tab. 13.

UMTS is the mobile cellular system, which should provide the services independently of user location (outdoor, indoor) and user speed (stationary, pedestrian, in-car or high speed train). WLAN networks are mostly restricted to the indoor usage, which also limit the subscriber speed, when compared to UMTS. The BWA based on IEEE 802.16 is the fixed wireless access system, thus it serves better as an interconnection of WLAN hot spots or delivers the service directly to the customer premises.

The QoS provisioning in UMTS is designed so that all types of services should be available (from real-time services up to e-mail downloading). In WLAN the issue of

QoS provisioning is commonly worse then in BWA based on IEEE 802.16 or UMTS. The QoS provisioning in case of IEEE 802.16 and UMTS is very similar. Maximum data rate that one user in UMTS can obtain is 2 Mbps. Note that such user would consume significant portion of available radio resources in the cell. WLAN or BWA systems can provide much higher bit rate to the single user compared to UMTS. BWA can provide up to 134.4 Mbps and WLAN based on IEEE 802.11 up to 54 Mbps.

The big disadvantage of UMTS are very high implementation costs, which will very likely restrict the are where the system will be deployed in large cities with high population density. In UMTS the implementation costs are very high due to in some countries even "astronomical" prices for licenses and very high costs for technology as well as for acquisition and rental costs for housing the technology. Note that the number of base stations needed is very high. On the contrary the WLAN networks are relatively very cheap to implement, because it operates in license free band, low price of technology and commonly almost zero cost for acquisition and housing. The implementation costs of BWA networks are larger then in case of WLAN, because it would be necessary to built network infrastructure outside operators premises and also the frequency band is likely to be not license free.

From the radiowave propagation point of view, UMTS is a system with NLOS availability requirement. The most significant signal loss factors are attenuation of neighbor obstacles (e.g. man made structures), reflection and diffraction. Signal attenuation due to vegetation is sometimes also considered when needed. Because the operating frequency is low, rainfall attenuation is negligible. Multipath propagation, moving user and movement of surrounding obstacles (e.g. cars) cause significant signal fading. Diversity techniques are commonly utilized at Node B site to overcome signal disruption. In case of WLAN based on IEEE 802.11, service availability in NLOS case is also required. Surrounding obstacles (e.g. building walls) causes the most significant attenuation. Signal fading due to multipath propagation must be considered as well. Diversity techniques are often used on both AP and terminal site. Since the WLAN services are commonly provided inside buildings and since the operating frequency is well below 10 GHz, rainfall attenuation and vegetation attenuation is not considered. BWA systems are commonly LOS systems. Signal attenuation is caused mainly by rainfall attenuation. When the tree shadows the terminal, vegetation loss must be considered as well. Moreover the signal fading caused by moving tree should also be considered.

8. Conclusion

In this paper we provided a basic overview of different types of communication systems, namely UMTS, WLAN based on IEEE 802.11, IEEE 802.16 and UWB. The comparative analysis has been given as well to highlight the applicability of the systems in different propagation environments, QoS provisioning and system performance under different conditions.

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	UMTS	WLAN			BWA		MBWA IEEE802.20
		802.11a	802.11b	802.11g	802.16	802.16aOFDMA version	
Propagation environment	Indoor/Outdoor Outdoor-to-Indoor NLOS	Indoor NLOS	Indoor NLOS	Indoor NLOS	Outdoor LOS	Outdoor Outdoor-to-Indoor LOS	Indoor/Outdoor Outdoor-to-Indoor NLOS
Loss factors	free space loss, surrounding obstacles (buildings)	free space loss, surrounding obstacles (walls)	free space loss, surrounding obstacles (walls)	free space loss, surrounding obstacles (walls)	free space loss, rainfall	free space loss, rainfall	free space loss, surrounding obstacles (buildings)
Fast fading	yes	yes	yes	yes	yes (when terminal shadowed by tree)	yes (when terminal shadowed by tree)	yes
Typical cell radius	500 - 1000 m	70 m	90 - 550 m	90 - 550 m	5 000 m	10 000 m	100 - 2000 m
User mobility	<200 kmph	4kmph	4kmph	4kmph	0kmph	0kmph	<250 kmph
Max. user bit rate	2 Mbps	54 Mbps	11 Mbps	54 Mbps	96/120/134.4 Mbps (20/25/28 MHz chan)	18.2 Mbps (6 MHz channel)	4 Mbps (5 MHz channel)
QoS provisioning	For all types of services	For delay tolerant services with not-guaranteed throughput	For delay tolerant services with not-guaranteed throughput	For delay tolerant services with not-guaranteed throughput	For all types of services	For all types of services	For all types of services
Frequency band	2GHz	5GHz	2.4GHz	2.4GHz	10 - 66 GHz	2 - 11 GHz	<3.5 GHz
Channel bandwidth	5MHz	20MHz	20MHz	20MHz	20/25/28MHz	6MHz	1.25/5MHz
Multiple access scheme	WCDMA	CSMA/CA	CSMA/CA	CSMA/CA	TDMA	FDMA	-
Modulation	BPSK - uplink QPSK - downlink	BPSK/QPSK/16-QAM/ 64-QAM	BPSK/QPSK/CCK	BPSK/QPSK/CCK	QPSK/16-QAM/ 64-QAM	QPSK/16-QAM/ 64-QAM	-
System application	Since cost of UMTS system is very high due to licenses, acquisition and technology, UMTS should be used to cover large areas with high population density and providing "all" types of services to millions of customers of all target groups.	WLAN based on IEEE 802.11 is most appropriate to cover small areas with high population density (hot spots) like business centers, commercial buildings or airports. Target group of customers is mainly in the commercial sector. It is most appropriate for services commonly available in traditional LAN networks, moreover giving the subscriber possibility to move. Since it operates in un-licensed band without acquisition cost requirements, IEEE 802.11 is very cheap solution.			IEEE 802.16 BWA system is best suited for "all" types of services. It provides large bandwidth to the subscribers, but without their mobility. Target group of customers is mainly in the commercial sector, but within private sector many services might be offered as well. Cost of BWA system is relatively high due to acquisition requirements and licenses.		-

Tab. 13 Comparative analysis overview