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1 Introduction

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UMTS Forum Report 28
by TDD Ad-hoc Group

Relative Assessment of UMTS TDD and WLAN technologies

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This report has been produced by the UMTS Forum, an association of telecommunications operators, manufacturers and regulators. The UMTS Forum comprises IT and media industries interested in broadband mobile multimedia that are active both in Europe and other parts of the world and who share the vision of UMTS (Universal Mobile Telecommunications System). These are key industry members of the Forum and have contributed significantly to this report. In terms of a technology platform UMTS will move mobile communications forward from today's environment to the Information Society incorporating third generation mobile services that will deliver speech, data, pictures, graphics, video communication and other wideband information direct to people on the move. UMTS UTRA (Universal Terrestrial Radio Access) is a member of the IMT-2000 family of standards.

This report is one of the series of UMTS Forum reports. It deals with technical views on UMTS TDD and WLAN technologies.

The views and conclusions in this report are purely those found and expressed during the work of creating this document and exempts National Administrations who are UMTS Forum members from being bound to them.

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First edition, rev. 1.0

1 Introduction

This report is another Report from the UMTS Forum to the impact of WLANs on 3G. Earlier reports (UMTS Forum Reports #22, #24 and #25) deal with quantitative and qualitative aspects [1, 2] as well as with WLAN spectrum and regulatory aspects [3]. In its Report #22 “Impact & Opportunity: Public Wireless LANs and 3G Business Revenues” UMTS Forum concluded that UMTS/3G and Wireless LAN are complementary rather than competitive technologies.

This report has been prepared by UMTS Forum with the following objectives:

- To carry out UMTS TDD market survey to obtain information on likely market introduction of TDD, status of manufacturers developments, features of TDD terminal and infrastructure equipment, etc.
- To provide a relative assessment of UMTS TDD & WLAN technologies.

Section 2 describes the results of the UMTS TDD market survey. This market survey covers industry activities and views on TDD. A questionnaire was distributed to all members of the UMTS Forum. Overall, eight completed responses were received by the UMTS Forum Secretariat. The reader is reminded that the sample response is too small to be statistically representative of the plans and intentions of the UMTS/3G operators and vendors as a whole. Therefore, the results of the TDD survey in section 2 must be carefully viewed with this in mind.

Section 3 provides a high level overview of UMTS TDD technology, including traffic capacity etc.

Section 4 of the report provides a comparison of UMTS TDD and WLAN technology from a deployment scenario perspective and compares the overall system capabilities of the two technologies.

Note on TDD Terminology: 3GPP standards distinguish between two types of UMTS TDD technology, which are characterized by different chip rates and consequently different bandwidths. Specifically the chip rates are 3.84 Mcps and 1.28 Mcps, with the corresponding bandwidths being 5 MHz and 1.6 MHz. Accordingly, the two TDD types are referred to in literature as Wideband TDD (WTDD) and Narrowband TDD (NTDD) or as High Chip Rate (HCR) TDD and Low Chip Rate (LCR) TDD. In this report, HCR/LCR TDD terminology is used.

2 Results of the TDD Market Survey

In Spring 2002 eight members of the UMTS Forum participated in a confidential survey regarding their outlook for TDD deployment. The survey was designed by members of the UMTS TDD Ad-hoc Group. Survey results were compiled and summarized by Strategic Resource Partners LLC, an independent marketing/research consultancy. Participating in the survey were:

- Four operators (European)
- One regulator
- One equipment manufacturer
- Two "other" types of companies (e.g. chip and applications providers).

It should be noted that because of the limited size of the survey, this CANNOT be viewed as a representation of the market. No market conclusions should be extrapolated from this research.

2.1 Outlook for TDD Deployment

Generally, the equipment manufacturer and "other" companies were more optimistic regarding the timing and breadth of TDD product introductions (believing 2003/2004 will likely see terminal introductions and service, while the operators and regulator thought 2004-2006 were more likely).

Expectations for TDD-HCR are more favorable than for TDD-LCR. The operators and regulator, especially, have lower expectations for TDD-LCR, expecting low penetration and little service activity during the next decade.

TDD-HCR market potential is expected to be less than 10% in 2004, increasing to 10-50% by 2009. Introduction of TDD-HCR is expected by most survey participants between 2004 and 2009. Supporting this forecast are the following:

- One operator and both "other" companies have specific strategy and development plans in place for TDD-HCR
- Field trials are planned prior to 2006 by two operators, the equipment manufacturer and both "others"
- Services perceived to have the greatest potential include Mobile Internet/Intranet/Extranet, MMS and Customized Entertainment.

None of the operators who participated in the survey are planning filed trials for TDD-LCR, nor do any expect introduction prior to 2009. Interestingly, the equipment manufacturer and both "others" are planning field trials for TDD-LCR simultaneously with TDD-HCR.

2.2 Impact on Infrastructure Configurations

Most expect to integrate TDD with FDD, rather than as an add-on. All plan to support base stations with ATM and IP, and Release 4 was most often mentioned as the likely RAN connection. Interest in TDD deployment (especially among the operators) was limited to Pico and Micro TDD base stations, with plans to provide these in the 2004 to 2006 timeframe. While operators were only considering TDD-HCR base stations, the equipment manufacturer and "other" companies expected similar timing for TDD-LCR base stations.

IP, Iucs and Iups are planned to support TDD-HCR RNC to CN interfaces. IP and Iub are planned for RNC to BTS. There were no common patterns for plans regarding RNC, smart antenna and base station locations.

2.3 Impact on Terminals

Respondents to the survey believe that by 2006 there will be market opportunity for all terminal types (GSM/GPRS/HCR-TDD, GSM/GPRS/FDD/HCR-TDD, CDMA2000/LCR-TDD, FDD/HCR-TDD only, HCR-TDD only, and LCR-TDD only). By 2006 most thought 1-10% of handsets and terminals will have TDD-HCR capability, increasing to 1-50% by 2010. Expected to be available by 2006 (TDD-HCR terminals) are voice and data handsets, smart phones, PDA's, PC cards and other data-only terminals. Again, only the equipment manufacturer and "other" companies believe TDD-LCR terminals will follow this schedule, as well.

Most believe that the most required 3G functionality for terminals will be Web browser and large LCD display.

2.4 ASICs and Software

Only one operator answered this set of questions, and along with the equipment manufacturer and "other" companies agreed that components would likely be designed for multi-mode terminals (rather than TDD only). Additionally, the operator anticipates a TDD-HCR software stack, while the equipment manufacturer and "other" companies expect multiple software stack options. These same companies believe that the Multi-mode 3G, FDD/TDD-HCR and 2G/3G TDD chip set solutions will each represent 25%+ of their mix to support TDD.

2.5 Test Equipment

This set of questions was answered by only two operators and the two "other" companies, with varied expectations:

- One operator believes test equipment will be available in 2003, the other in 2007
- Both "other" companies believe test equipment will be available in 2003.

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3 UMTS TDD System Overview

UMTS uses wideband code division multiple access (W-CDMA) as its air Interface. The W-CDMA technology, as specified by the 3GPP as one of the proposed 3G standards, supports two modes of operations: Frequency Division Duplex (FDD) and Time Division Duplex (TDD). The TDD mode uses unpaired spectrum bands and provides users with additional capacity indoors and in outdoor areas.

WCDMA TDD-mode can provide multiple users 384 kbps uplink and/or downlink data capability. With a single user down link, (DL) data capability is 2 Mbps. Like FDD, it supports voice. In a synergetic relationship with WCDMA FDD and/or GSM/GPRS, TDD can provide higher rates and additional capacity in hotspot areas.

National regulatory bodies have endorsed the proposed three-tiered network deployment and have allocated paired frequency bands for FDD, unpaired licensed frequency bands for TDD as well as unlicensed bands for TDD.

The combination of FDD technology and TDD technology in third generation UMTS can result in significant technological and financial benefits, including improved Return on Investment for network operators, equipment manufacturers and application developers. TDD can leverage the infrastructure of a “first-wave” FDD-only rollout of 3G, which can further reduce the cost of deployment, by being a part of a multi layered hierarchical deployment strategy. National regulatory bodies have endorsed the proposed three-tiered network deployment and have allocated paired frequency bands for FDD, unpaired licensed frequency bands for TDD as well as unlicensed bands for TDD. Furthermore, TDD can offer both consumers and corporate users continuity of user experience when using their handheld devices, smart phones and PDAs. These benefits arise from the basic advantages of TDD compared to WLAN technologies:

- TDD is harmonized with FDD at the chip rate level, making TDD functionality a highly cost-effective complement to existing FDD designs.
- TDD is fully and seamlessly integrated with FDD in the UMTS air interface standards and provides an opportunity for operators to make the most of their allocated 3G unpaired spectrum whilst exploiting the inherent integrated user mobility and service roaming features of FDD and TDD.
- TDD can provide to multiple simultaneous users high-speed data capability of 384 kbps (with a maximum DL data capability of 2 Mbps for one user).
- TDD is cost-efficient for network deployment. It offers scalable capacity for "hot spots," where combined voice and data traffic must be served efficiently, through a tiered architecture which may include macro, micro, and picocells.
- TDD can provide an attractive wireless data solution for wide area coverage and islands of coverage where there is a need for wireless ADSL services and outdoor Wireless LAN like services.
- TDD can adopt techniques such as channel sensing and adaptive antennas in order to improve performance, coverage and capacity.

3.1 TDD Traffic Capacity and Flexibility

TDD is a flexible air interface for asymmetric bursty data applications. This capability is important as the number of wireless Internet applications and multi-media services for consumers and corporate/business users increase over the next few years.
TDD can provide users with flexible data rates and facilitate the uplink and downlink resource sharing. TDD provides this functionality by defining resources in all three multiplexing domains: time, frequency, and code.

3.2 TDD Deployment Guidelines

Deployment issues related to FDD and TDD are currently being worked by ITU Working Party 8F (http://www.itu.int) and 3GPP RAN Working Group 4 (http://www.3gpp.org). The topics being considered include (non exhaustive):

- Distance between antennas
- Coordination between Operators
- Antennas Patterns
- Necessary attenuation levels
- Filtering

4 Relative Positioning of UMTS TDD and WLAN Technologies

In 2002 and early part of 2003, the UMTS Forum published a number of reports dealing with WLANs and their impact on UMTS. Report #22 entitled "Impact & Opportunity: Public Wireless LANs and 3G Business Revenues" concludes that UMTS/3G and Wireless LAN are complementary rather than competitive technologies, and that Public WLAN service may be an important source of competitive differentiation for 3G operators [1]. Report #24 [2] and Report #25 [3] describe a Qualitative Market Survey and WLAN Spectrum respectively. The present report provides a relative assessement of WLAN and TDD in a technical sense.

In this section, a comparison of the two technologies is first provided followed by considerations for deployment. At the very outset, it must be realized that WLAN technologies were originally developed for wireless data communications, which are typically dominated by non-real-time services. However, WLAN technologies are evolving to meet the needs of the impending convergence of data communications and telecommunications. In contrast, TDD technology was developed as a 3rd generation technology in anticipation of the converged data and telecommunications, making it ready for wireless voice, data and multimedia communications.

The technical comparison of WLAN and TDD technologies presented here addresses the following aspects: System & Service Attributes and System Performance. System & Service Attributes include Spectrum issues, Susceptibility to Interference, Mobility, Scalability, Support for Voice & Data Services, Security and Quality of Service. System performance includes Radio Link characteristics, Data link rates and User throughputs, Cell Coverage as a function of number of users & range, Cell planning & System Capacity. As a result of such a comparison, we will be able to elucidate a number of considerations needed for WLAN and TDD deployments.

4.1 System & Service Attributes of WLANs

There are a number of candidate technologies for WLANs. Dominant are the IEEE Standards 802.11, 802.11b and 802.11a. While 802.11 is mostly of a historical interest, 802.11b is being deployed most currently and 802.11a could be a next evolutionary step. Another development is 802.11g, which is also an evolutionary step to 802.11b while maintaining some level of backward compatibility. HiperLAN is another standard that has been developed for what was conceived to be the next generation wireless LAN, but does not appear to be gaining traction in the industry.

802.11b WLAN systems offer essentially a wireless scheme for the transport of IP-packets based on collision-based multiple access and operate in the unlicensed ISM frequency band in the U.S. (Other countries use slightly varying spectrum allocations for this purpose.) The spectrum allows for 11 radio channels, although only 3 radio channels do not overlap with each other with channel spacing of 25 MHz. This has impact on WLAN deployment over a large geographical area with channel reuse. Each radio channel occupies approximately 22 MHz bandwidth and supports 'instantaneous' link data rates of 1, 2, 5.5 & 11 Mbps, with the actual rate being determined essentially by the signal to noise ratio. 802.11b does not support power control, so that the instantaneous link data rates become directly dependent on range between the Access Point and the User Equipment. (Access Points play a role similar to Node-B/BTS in UMTS/GSM systems.) The radio channels are shared by multiple users by a collision-based multiple access scheme known as CSMA/CA. Within this MAC scheme, there are essentially 3 variants, simple DCF, DCF with RTS/CTS and PCF. Of these DCF is the most used protocol and it allows all users equal opportunity to send and receive data. DCF with RTS/CTS allows users to randomly access the radio channel to reserve the channel for a period of time. PCF allows for coordinated allocation of resources to various users. In practice, simple DCF is the most deployed. The air interface is very simple, with rudimentary QoS controls and with rather simple radio link encryption capabilities. User Authentication is typically handled outside the 802.11b standard and by layers above the IP-layer. The radio interface is not optimized for high speed mobile User Equipment, so that the 802.11b technology is typically characterized as being best suited for nomadic wireless User Equipment, such as Laptop PCs. Accordingly, the power consumption, especially during inactivity periods, was not minimized through either protocol design and/or through chip & system designs. The 802.11b standards focused mostly on the radio interface so that communications between Access Points is not sufficiently well developed. This makes mobility (location) management and handover of User communication between Access Points vendor dependent and makes multi vendor interoperation difficult. Finally, we mention in passing that 802.11b standards allow direct peer-to-peer communication without the involvement of the Access Points.

As 802.11b based WLAN systems are being deployed at an increasing rate in the public (in contrast to private – enterprise & home -) environments, the standards are being evolved to address several shortcomings alluded to above. For example, 802.11i is improving the encryption capabilities, whereas 802.11e is seeking to improve QoS controls. Similarly, 802.11f is developing protocols for Inter Access Point communication that will facilitate standardized methods for handovers.

Partly to overcome the limitations of crowding of the 2.4GHz ISM spectrum where 802.11b operates, and partly to increase the data rates, the 802.11a standard was developed in the license-exempt 5GHz band. This spectrum supports up to 12 non-overlapping channels, with each channel still occupying 20 MHz bandwidth. However, using a different modulation technique, the instantaneous data rates are increased to 6,9,12,18,24,36,48 & 54 Mbps. However, the MAC layer essentially stayed the same, leaving the remaining attributes of the 802.11a based systems essentially equivalent to those of 802.11b based systems. Presently, chipsets as well as devices are being introduced into the market and its deployment success is yet to be seen.802.11g is an evolution of the 802.11b standard in the same frequency band (ISM in US), while increasing the data rates up to 54 Mbps. Industry products based on this standard are in their infancy stage and it remains to be seen how they will develop in future, considering the spectrum crowding and competitive positioning of 802.11a systems.

Finally, a critical attribute of the WLAN systems is that they are essentially designed to be stand-alone local area networks. As such, the connection of WLAN 'islands' to a backend network is not standardized. Typically, the backend network provides user application services (such as Internet access) as well as subscriber management (consisting of user authentication, billing and customer care). A current development is to solve this problem by providing and standardizing interfaces to 3G Core Networks. This WLAN-3G Interconnection/Interworking is presently a hot topic of standardization in 3GPP/SA and a topic of roaming and security issues in GSMA. The work so far has identified a number of levels of interworking ranging from loose interworking to tight interworking. The loose interworking begins at simply providing common billing and moves to common access control (i.e. common authentication) and finally addresses seamless operation (including handovers) between WLAN and 3G networks. The current focus is on common billing and common access control and the completed standards will likely consume a good part of 2003. Standardizing tighter levels of interworking will no doubt take much longer.

4.2 Comparison of UMTS TDD & WLAN System & Service Attributes

In this section, TDD systems are compared with mostly WLAN systems based on 802.11b technology. However, since 802.11a and 802.11g systems use the same MAC layer and differ only in the PHY layer, most our comparisons will also hold for WLANs based on these technologies. We shall follow the same order as was used in enumerating the system and service attributes in section 3.1. Unless explicitly stated, WLAN denotes 802.11b based WLAN in this section.

Firstly, while WLANs provide for wireless transport of IP-packets, TDD systems provide for wireless transport of IP-packets as well as real-time data generated by sources such as AMR Voice-Coders. In other words, TDD provides both Circuit Switched and Packet Switched services, whereas WLANs provide only Packet Switched services. Thus TDD systems are readily capable of supporting real-time, conversational services, including Voice as well as Multimedia services.

WLANs enable multiple users to access the radio interface using simple collision-based algorithm known as CSMA/CA, whereas TDD systems use highly sophisticated MAC algorithms. The TDD MAC algorithms enable providing radio resources to various users in a manner optimised for their services. Thus it will follow that inefficiencies due to MAC algorithm are less in TDD compared to WLAN systems.

WLANs use free unlicensed frequencies, whereas TDD systems use licensed and unlicensed frequencies. While this is attractive for private deployment of WLANs, public commercial deployment of WLANs in the unlicensed frequencies is presently under the scrutiny of regulators in various countries. On the other hand, the fact that WLANs utilize unlicensed frequencies implies that these systems are highly vulnerable to interference from other devices operating in the same frequencies, and furthermore the interference is unpredictable and uncontrolled. Such interference could arise from Bluetooth devices, advanced cordless phones, microwave devices, and possibly from other WLAN networks.

Licensed TDD systems are free from such uncontrolled and unpredictable interference from other devices operating in the same frequency band. The sources of interference in TDD systems are well understood and some of them can actually be taken into account in advanced receivers. An example is a MultiUser detector, which detects the signals of all interfering users in a given cell and cancels them out.

Whereas 802.11b based WLANs have only 3 non-overlapping radio channels, TDD systems have many more radio channels, providing greater degrees of freedom in multi-cell system design. TDD has more radio channels because they are defined in terms of Scrambling Codes.

The maximum instantaneous link data rate supported by WLAN is 11 Mbps in 25 MHz (0.44 Mbps per MHz) in one direction (uplink or downlink). User applications do not experience this instantaneous data rate, but only a throughput, which is smaller due to signalling overheads, idle times, etc. It will be shown later in section 3.3 that the theoretical maximum throughput is about 7 Mbps in 25 MHz (0.28 Mbps per MHz). In comparison, the maximum instantaneous data rate for TDD, calculated in the same way based on chip rates, would be 3.8 Mbps in 5 MHz bandwidth (0.77 Mbps per MHz). TDD can sustain a maximum downlink user throughput data rate of 2 Mbps in 5 MHz (0.4 Mbps per MHz).

In WLANs at 2.4 GHz, there is no power control mechanism, so that the data rates depend directly on range. As such, the data rates typically step down from 11 Mbps to 1 Mbps as the range is increased. This produces a non-uniform user experience within a cell. In contrast, TDD has sophisticated power control mechanisms, so that the instantaneous data rates could be supported with reduced dependence on range. This feature enables a user experience that is less dependent on the location of the user relative to the Base Station (Node-B/BTS).

Unlike the WLAN air interface which has only rudimentary QoS controls, TDD allows sophisticated control of QoS. The Quality of Service provided by TDD can be controlled in terms of the delay, priority, mean data rates, etc. This enables enhanced user experience in supporting a variety of real-time circuit-switched services as well as packet switched services.

The security of TDD systems provides for strong User Authentication, User Confidentiality as well as User Data Privacy (via encryption). The algorithms used are strong and have been time tested. As stated before, User Authentication has to be achieved outside of the WLAN systems and User Confidentiality is not available. The WLAN encryption algorithm (called WEP) uses a 64 bit or 128 bit key and has been shown to be easily broken.

Unlike WLAN air interface, the TDD air interface is designed for working efficiently in mobile environments as well as nomadic environments. In particular, mobile environments produce large multipath delay spreads as well as Doppler frequency shifts. Most WLAN receivers cannot handle such parameters. Although from a practical point of view, this may not be an issue for Laptop PCs, WLANs are being integrated into portable devices such as Wireless PDAs, for which this may become an issue.

Power consumption in WLANs has not been minimised either at the protocol level or at the chip & device level, so that their application into the portable device market may face challenges. For example, there is no power control protocol and there is no intelligent management of inactivity periods (idle/sleep/doze mode operations). In contrast, TDD air interface is optimised for minimal power consumption and ideally suited for portable device application. Specifically, TDD air interface employs sophisticated power control as well as idle/sleep mode operations. TDD chips and devices are typically designed for optimal power performance.

It has been pointed out that WLAN standards do not fully specify the functions needed to support mobility (location) management and handovers between Access Points. TDD systems work with the Core Network and support full mobility management as well as handovers of calls and sessions in progress. The mobility (location) management features become extremely important for integrating WLANs into 3G systems as well as for Roaming between WLAN networks.

It can now be seen that most of the above comparisons are also applicable for 802.11a based WLANs. The only places where some relief is obtained are the availability of a larger number of radio channels (12 as compared to 3) and higher data rates per MHz.

Finally, we address the connectivity to the mobile core network. Clearly, TDD was designed to be an integral part of the 3G system, so that TDD systems have all the necessary interfaces and services defined and standardized to the 3G Core Network. These interfaces provide not only user authentication, billing, customer care but also access to all services of the Core Network (such as IMS services). Furthermore, TDD systems enable seamless operation, including handovers, with the wide area access network (e.g. FDD or GSM/GPRS). On the other hand, the interconnection and interworking between WLANs and 3G Core Network is only now being addressed by the 3GPP standards body and is likely to take a number of years for full completion.

4.3 Performance of 802.11b WLAN Systems

We shall summarize some main performance results of 802.11b based WLAN systems, when deployed in a typical indoor environment. It is to be noted that the data presented depend upon various assumptions and methodologies, which are described in the included references. However, caution must be exercised in translating the data to other scenarios.

We shall address the following aspects: Radio Link characteristics, Data link rates and User throughputs, Cell Coverage as a function of number of users and range, Cell planning and System Capacity. The data is taken from a number of public domain papers as well as some specific studies done by InterDigital Communications Corporation. Results for 802.11a systems as well as for outdoor deployment would be different in numbers but similar in a qualitative sense.

The link performance may be characterized by the Eb/No required for a typical 10% Packet Error Rate for Packet Sizes from 64 Bytes to 1Kbytes in an indoor environment with channel delay spreads ranging from about 100 to 300 nsecs. Depending upon the specific receiver type, the required Eb/No ranges from about 5 dB to 7 dB for 11 Mbps operation. Other data rates and delay spreads result in appropriate changes to the Eb/No value. [4, "TGb proposal comparison matrix", IEEE P802.11, doc IEEE802.11 98/276, July 1998].

The instantaneous data link rates for 802.11b are 1, 2, 5, and 11 Mbps. However, the long term averaged data rate experienced by the user, termed throughput, is considerably smaller due to the following reasons: Idle times necessitated by the multiple access schemes CSMA/CA and Overhead data bits used as headers, etc. Taking these into account, the maximum possible user data throughput reduces to 7.4 Mbps (67% of the instantaneous data rate of 11 Mbps). Similarly, the throughput rates reduce to 4.4, 1.8 & 0.9 Mbps for 5.5, 2 & 1 Mbps data link rates. [4, "TGb proposal comparison matrix", IEEE P802.11, doc IEEE802.11 98/276, July 1998].

The throughput rates discussed above are the best possible rates, experienced by, for example, a single user very close to the Access Point. As the number of users increases, there will be collisions between the data packets from different users, resulting in reduced throughput rates. Similarly, as the channel quality decreases, either due to increased range or increased interference, there will be packets received in error. Such packets will need to be retransmitted, further reducing the throughput rates. Figure 3.3-1 shows how the aggregate throughput rates decrease as a function of range and as a function of the number of user for an assumed 10% Packet Error Rate. It is clear that the aggregate throughputs fall to less than 3 Mbps at some 60 meters range for 100 users, which results in a rather small 30 Kbps per user! The users are randomly placed over the entire cell and the throughputs are averaged. [5, "Measured Performance of 5 GHZ 802.11a Wireless LAN systems", by James C. Chen, Jeffrey M. Gilbert, Atheros Communications, 08/27/2001 & InterDigital Studies].

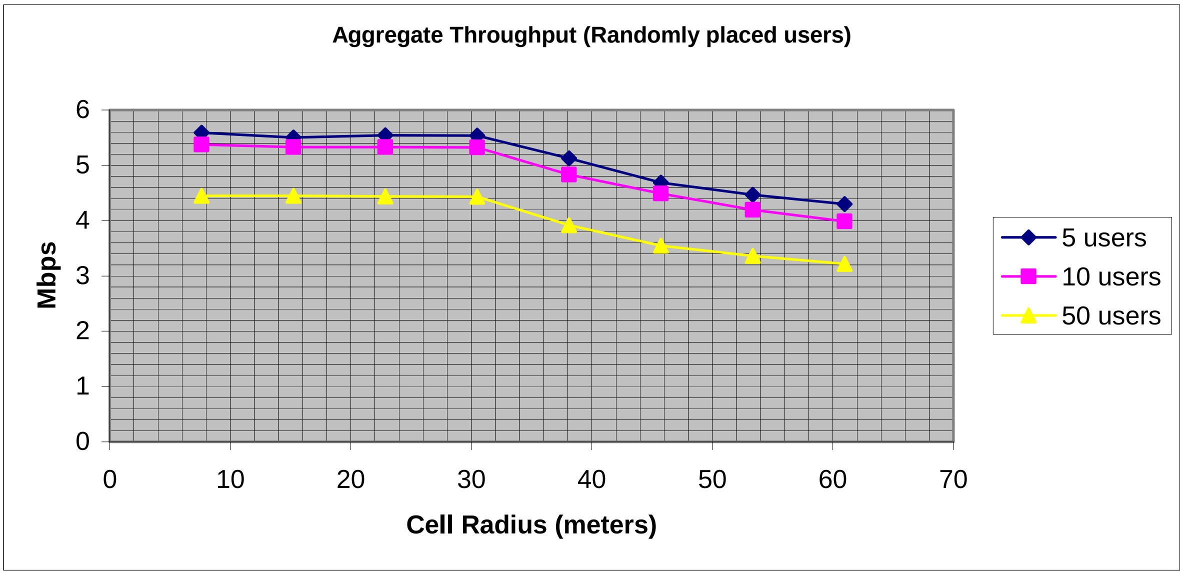


Figure 3.3-1. Aggregate Throughput of 802.11b based WLANs.

Finally, we address the issue of planning a large coverage area with a number of WLAN cells. 802.11b spectrum allows for only 3 non-overlapping radio channels, resulting in a small 3-cell reuse factor as shown in Figure 3.3-2. This results in a significant amount of interference from cells using the same frequency radio channel (co-channel interference), which in turn limits the aggregate throughputs. Clearly, the degradation is the most when the cell radius is small. The corresponding throughput results are shown in Figure 3.3-3. [5, "Measured Performance of 5 GHZ 802.11a Wireless LAN systems", by James C. Chen, Jeffrey M. Gilbert, Atheros Communications, 08/27/2001 & InterDigital Studies].

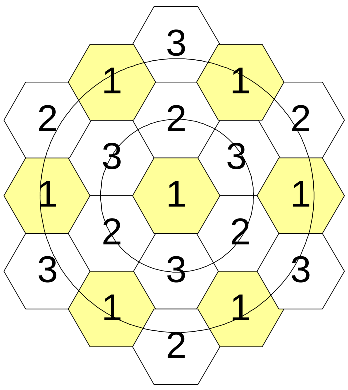


Figure 3.3-2. Cell Layout.

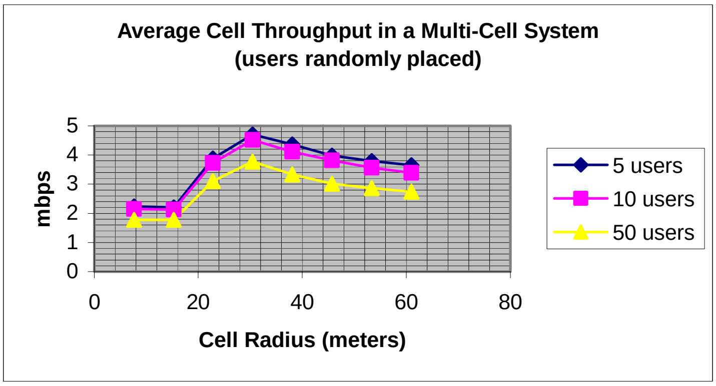


Figure 3.3-3. Cell Throughput (Capacity).

The above results are for example indoor deployment. In an outdoor scenario, similar results hold good, except that the range is enhanced from some 60 meters to about 200 meters. Furthermore, the above results assume that the MAC algorithm is based on a simple DCF, so that RTS/CTS and PCF are not modeled.

Similarly, although the above results are presented for 802.11b based WLANs, the qualitative behaviour of the results holds good also for 802.11a and 802.11g. While their higher instantaneous data rates will increase the absolute value of the throughput rates, their degradation as a function of number of users and range will remain similar. A reason is that the MAC layer is the same for all these standards. As new MAC algorithms are introduced in 802.11e, some of these trends could change.

4.4 Comparison of UMTS TDD & 802.11b WLAN System Performance

In this section, we shall compare the TDD and 802.11b WLANs from the Link, Cell and System performance points of view. It is to be noted that the data presented depend upon various assumptions and methodologies, which are described in the included references. However, caution must be exercised in translating the data to other scenarios.

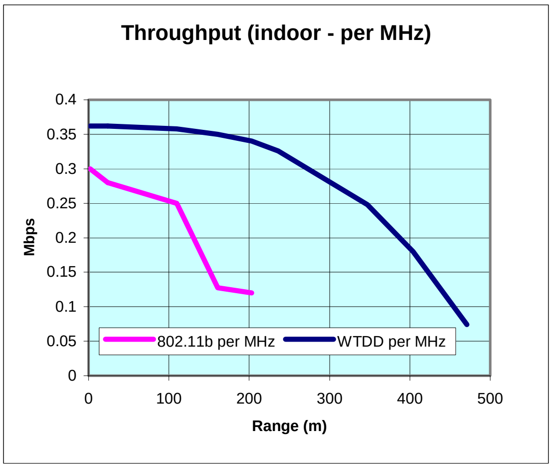
The link performance is essentially characterized by the required signal quality (Eb/No to achieve a target packet error rate in case of data services and bit error rate in case of voice) and user throughput. Whereas WLAN requires some 5-7 dB for 11 Mbps operation, TDD requires 2-6 dB for low mobility high rate data users. [4, "TGb proposal comparison matrix", IEEE P802.11, doc IEEE802.11 98/276, July 1998 and InterDigital Studies.]

Comparison of WLAN & TDD data rates is not straightforward because they are characterized differently in each system. For example, in WLANs, we have the instantaneous link rate (11 Mbps for 25 MHz carrier), the maximum throughput rate (reduced to 7.4 Mbps due to packet headers and guard times) and practical throughput rates (reduced to about 6 – 2 Mbps due to data collisions among the various users and range). Note that these rates are 'aggregate' rates, which are shared by all the active users in the WLAN cell. [6, "Throughput performance of Wireless LANs operating at 2.4 and 5 GHz", A. Kamermann, G. Aben, Lucent Technologies].

In TDD, one does not generally talk about an instantaneous link rate, but for the sake of comparison, it may be taken as 7.68 Mbps per 5 MHz carrier (3.84 Mcps times 2 bits per each QPSK-modulated-chip). This rate is reduced to user throughput rate by the following factors at the Physical Layer: 1) Spreading factor, 2) FEC (Forward Error Correction) overhead, 3) Synchronization-related overhead (such as midamble bits), 4) Guard times, 5) Common Signalling overhead (timeslots needed for common channels), 6) Dedicated Signalling overhead. There are additional overhead factors at higher layers, such as: 7) RLC and MAC header overhead, 8) Retransmitted Blocks in case of errors (if Acknowledged mode is used for RLC).

Of these link rate reduction factors, 3,4,5,6 & 7 are somewhat 'static' and are simply needed for multiple access structure and scheme. Taking these factors into account and making other assumptions (such as Burst type 2), the link rate would reduce to about 5.7 Mbps (74% of instantaneous link rate). [InterDigital Studies]. This is already superior to the WLAN multiple access overhead, which brings down the instantaneous link rates to 67%. [6, "Throughput performance of Wireless LANs operating at 2.4 and 5 GHz", A. Kamermann, G. Aben, Lucent Technologies].

The remaining rate reduction factors, namely 1, 2 & 8, are dependent on practical channel conditions. For example, higher spreading factors and higher FEC overhead lead to more robust data transmission and hence reduced retransmissions. While they reduce the user throughput rate, the rate is less affected by range (channel conditions). Furthermore, there are a large number of combinations of spreading factor values and FEC schemes that can be used for optimal performance. In contrast, WLAN standard does not specify FEC schemes and link performance relies entirely on retransmissions of erroneous data. Furthermore, transmit power control is an important element of TDD that provides for the robustness of data transmission. In addition, power control also provides the ability to maintain a constant user throughput rate by trading off transmitted power. In contrast, WLANs use fixed power for transmission and reduce the instantaneous link rate to account for channel losses. As a result of these two factors, the user throughput rates are much less affected by range in TDD compared to WLANs. Preliminary data supporting this claim are depicted in Fig 3.4-1. [InterDigital Studies].



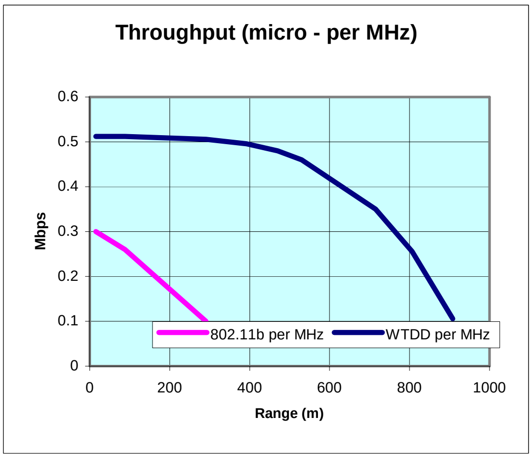


Figure 3.4-1. Comparison of WLAN & TDD Throughput/cell for indoor and outdoor-micro deployments.

Cell performance of the WLAN and TDD systems can be characterized in terms of coverage (throughput) performance as the number of users is increased. It has been shown in section 3.3 that the contention based multiple access scheme in WLAN causes the aggregate throughput to fall considerably as the number of users increases. (See Fig 3.3-3). In contrast, the TDD multiple access scheme is not based on contention basis, so that the aggregate throughput is less affected by the number of users. Strictly speaking, the time slotted nature of the TDD air interface as well as the discrete nature of the so-called 'Resource Units' causes some degradation, but it is conjectured to be relatively small. Secondly, the increased number of users results in increased multi-user-interference, but this is suppressed by advanced receiver algorithms, such as Multi-User Detection.

Thanks to the reduced dependence on range as well as the number of users, the user experience is more uniform in TDD across the coverage region of a cell compared to WLANs.

Finally, the system capacity in a multicell scenario requires cell planning and radio channel reuse, resulting in co-channel interference. As noted earlier in section 3.3, WLAN are limited to 3 radio channels, whereas TDD enables the separation of cells in the code domain in addition to the frequency domain. If required, cell planning could also exploit the time domain, by assigning different time slots to different cells. This allows for highly scalable systems using TDD technology.

4.5 Deployment Considerations for UMTS TDD & WLAN Systems

Firstly, we recollect the salient distinguishing aspects of TDD & WLAN systems, which have been elaborated in sections 3.3 and 3.4. They fall in the areas of license/unlicensed spectrum and susceptibility to interference, scalability, connectivity to mobile core network, security, QoS control, support for voice services and power consumption. The licensed/ unlicensed spectrum and susceptibility to interference issues suggest that WLAN is well suited to controlled environments such as indoor home and enterprise, whereas TDD is well suited to indoor enterprise as well as outdoor public environments. The scalability issue suggests that WLAN are well suited to hot spot coverage whereas TDD is well suited for hot spots as well as wider area deployments. The connectivity to mobile core network issue suggests that TDD systems can benefit from the subscriber management aspects (such as authentication, billing and customer care) from the core network, whereas WLANs require additional new (yet to be standardized) interfaces to the core network. The security, QoS control as well as the voice services issue clearly suggests that TDD systems offer mature proven solutions to these three aspects, whereas WLANs are evolving towards that direction. Finally, the power consumption issue suggests that TDD based devices permit low power hand-held user equipment, whereas WLAN based devices are likely to continue to serve the Laptop market well.

5 Definition of Abbreviations/Terms

3GPP	Third Generation Partnership Project
AP	Access Point
BS	**Base Station**
CSMA / CA	Carrier Sense Multiple Access / Collision Avoidance
DCF	Distributed Control Function
Eb/No	ratio of the Energy per bit to the spectral Noise density
FDD	**Frequency Division Duplex**
HCR	**High Chip Rate**
ISM	Industrial, Scientific and Medical (radio band)
LCR	**Low Chip Rate**
MAC	Medium Access Control
NTDD	**Narrowband Time Division Duplex**
PCF	Point Control Function
PHY	PHYsical layer
QoS	Quality of Service
RTS/CTS	Receive To Send/Clear To Send
TDD	**Time Division Duplex**
UTRA(N)	**Universal Terrestrial Radio Access (Network)**
WLAN	Wireless Local Area Network
WTDD	Wideband Time Division Duplex

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