Project	**IEEE 802.20 Working Group on Mobile Broadband Wireless Access** <**http://grouper.ieee.org/groups/802/mbwa**>
Title	**Basic Elements of a TDD MBWA Air Interface**
Date Submitted	**2003-03-06**
Source(s)	**See next page**
Re:	802.20 Contributions
Abstract	Temporary Cover Sheet to Supply Doc Number. This contribution will be replaced with the permanent cover supplied by the authors without change of Doc Number or revision indicator
Purpose	
Notice	
Release	

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Title	**Basic Elements of a TDD MBWA Air Interface**
Date Submitted	**2003-03-03**
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Re:	This contribution is submitted in response to the Call for Contributions from the chair of 802.20 for its March 2003 meeting.
Abstract	This contribution is an overview of basic elements of a TDD MBWA air interface.
Purpose	The authors desire that this proposal form the basis for the TDD MBWA air interface.
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Release	
Patent Policy	

Basic Elements of a TDD MBWA Air Interface

Marc Goldburg, Byung-Keun Lim, Kazuhiro Murakami

1 Introduction

This document proposes and describes a TDD air interface for MBWA. The proposed air interface fully complies with the 802.20 PAR. Additionally, the air interface proposed here is designed to maximally leverage adaptive antenna processing to achieve the PAR objectives. This document is an overview of a planned response to a future call for proposals for a TDD-based MBWA air interface.

2 Overview

The proposed air interface has a TDD/TDMA structure whose physical and logical characteristics have been chosen for the efficient transport of end-user IP data and to extract maximum benefit from adaptive antenna processing. The physical aspects of the protocol are arranged to provide spatial training data, and correlated uplink and downlink interference environments, for logical channels amenable to directive transmission and reception such as traffic channels. Conversely, channels not amenable to directive processing, such as paging and broadcast channels have smaller payloads and receive a greater degree of error protection to balance their links with those of the directively processed channels. Adaptive modulation and channel coding, along with uplink and downlink power control, are incorporated to provide reliable transmission across a wide range of link conditions. Modulation, coding and power control are complemented by a fast ARQ mechanism to provide as reliable link as is possible in a mobile wireless setting. Fast, low-overhead make-before-break inter-cell handover is also supported. Differentiated and tiered services are enabled through a flexible Quality of Service (QOS) mechanism. Security for the radio access link is provided by mutual authentication of the terminals and access network, and by encryption to ensure data privacy.

The proposed air interface has three layers designated as L1, L2, and L3. Table 1 describes the air interface functionality embodied in each layer. Each layer's features are briefly described below; more detailed overviews of key aspects are described in subsequent sections of this document.

Layer	Defined Properties
L1	Frame and burst structures, modulation and channel coding, timing advance
L2	Reliable transmission, logical to physical channel mapping, bulk encryption
L3	Session management, resource management, mobility management, fragmentation, power control, link adaptation, authentication

Table 1: Air interface layers

2.1 L1

L1 is characterized by a TDD/TDMA structure with 5 ms frames, each frame containing three uplink and three downlink bursts (timeslots). The air interface's logical channels are all mapped onto this structure. In the interest of providing high spectral efficiency, many aspects of L1 are specifically designed to support the effective use of adaptive antennas. For instance, training sequences for Spatial Division Multiple Access (SDMA) are incorporated in certain burst structures.

Uplink and downlink symbol rates are 500 kSymbols/s in all circumstances and a 25% root-raised cosine filter is employed, which leads to a 625 kHz carrier spacing.

The basic physical resource in the system is a spatial channel, which consists of a carrier, an uplink and downlink timeslot pair, and a spatial channel index. Multiple antennas and adaptive antenna processing make it possible to support multiple spatial channels simultaneously on the same conventional channel.

A range of modulation and coding combinations ("ModClasses") are employed to maximize throughput subject to FER and link conditions. Independent uplink and downlink power control and ModClass adaptation are to be performed on a burst-by-burst basis on traffic channels.[1] Channels that have lower spatial processing gain, such as broadcast and paging channels, are transmitted with more extensive channel coding than traffic channels, balancing the tolerable path loss for all channel types. L1 employs spatial processing, multiple modulation and channel coding formats, and equalization with per-burst training data to manage the RF challenges of a mobile Non-Line-of-Sight (NLOS) environment. L1 is to support per-user data rates in excess of 1 Mbps per carrier on the downlink and in excess of 300 kbps per carrier on the return link as demanded by the PAR.[2] Carrier aggregation multiplies these per-user data rates by the number of aggregated carriers.

2.2 L2

L2 maps control and data messages to physical resources and provides Acknowledged Mode (AM) and Unacknowledged Mode (UM) message delivery. AM data is delivered via a byte-addressable retransmission mechanism similar to that used in TCP, and provides a reliable delivery mechanism for L3 data including the preservation of byte ordering. Retransmission is done directly from the Base Station (BS) or User Terminal (UT) as appropriate to minimize ARQ latency. Traffic bursts are composed of tagged UM, AM, control and user data, allowing multiple messages to be sent in a single air interface burst for efficiency and low latency. L2 also provides bulk encryption to ensure the confidentiality of user and control data.

[1] The air interface allows User Terminals (UT) that support only low order (e.g., constant modulus) uplink ModClasses, enabling the usage of highly power efficient UTs for specialized applications.

[2] 802.20-02/01 - PAR Item 18

2.3 L3

L3 manages access to air interface resources. Once a UT has registered with a BS, no air interface resources are allocated to that UT unless upstream or downstream traffic needs to be exchanged between it and the BS. All resource allocation decisions are made centrally at the BS, governed, in part, by QoS considerations including per-user limits on data rate and priority. Carrier and timeslot aggregation is employed to increase per-user throughputs on traffic channels beyond those supported by a single carrier-timeslot pair. Finally, uplink and downlink spatial processing at the base station results in a highly efficient access mechanism that exploits SDMA in addition to conventional techniques such as collision detection/avoidance.

L3 also manages the relationship between the UT and the BS, maintaining the fundamentals of the association between those two entities that permits the exchange of end-user IP data. In addition, L3 employs physical measurements made at L1 to manage mobility and coordinate power control and link adaptation between the UT and the BS. L3 nominally receives end-user PPP or IP data from higher-level protocol entities. It provides for BS authentication so that the UT confirms the identity of the BS and vice versa.

3 Duplex

The proposed air interface employs a TDD duplexing structure. Not only is this responsive to the 802.20 PAR[3], it is also appropriate for a packet data system intended to operate in licensed spectrum with high spectral efficiency. It is well known that TDD duplex schemes derive the highest spectral efficiency benefits from adaptive antennas.[4] Worldwide, available spectrum for licensed mobility operations below 3.5 GHz is increasingly scarce and fragmented; air interfaces designed for unpaired spectrum provide potential spectrum licensees with flexibility in their spectrum acquisition strategies. TDD also allows the uplink/downlink asymmetry of the air interface to match the average, long-term uplink/downlink asymmetry of the traffic, leading to more effective spectrum utilization.

In general, any duplexing and multiple access structure imposes requirements on the air interface for spectrally efficient operations. With a TDD/TDMA structure, synchronization of the base stations ensures that downlink transmissions in one cell will not present interference to uplink transmissions in a neighboring cell and vice-versa. Synchronization is economically and effectively provided at the BSs through GPS or another reference timebase with adequate stability. UTs, in turn, employ timing advance to synchronize to the BS frame structures. Additionally, a range extension period is included in the frame to allow the UT to completely receive a delayed signal from the BS prior to transmitting its own timing-advanced signal. Section 5 discusses the range extension period in greater detail.

[3] 802.20-02/01 - PAR Item 18
[4] See C802m_ecsg_02/03 and C802.20-03/05

4 Logical Channels and Burst Types

A UT and a BS exchange information using a small number of logical channels. These logical channels, listed in Table 2, are mapped to physical bursts for transmission. There is a Standard Uplink and a Standard Downlink burst type common to the RACH, TCH, CCH in the downlink and FACCH logical channels. The remaining logical channels, namely PCH, BCH, and CCH in the uplink, are transmitted by dedicated burst types.

Burst Type	Symbol	Logical Channel
Downlink bursts:		
Frequency Synchronization	F	BCH
Timing Synchronization	T	BCH
Broadcast	B	BCH
Page	P	PCH
Standard Downlink	D	RACH, TCH, CCH, FACCH
Uplink Bursts:		
Configuration Request	C	CCH
Standard Uplink	U	RACH, TCH, FACCH

Table 2 Burst types

4.1 BCH

The Broadcast CHannel (BCH) is a downlink-only channel and the first logical channel the UT uses in establishing a connection to the BS and subsequently to the backhaul network. The BCH consists of the F, T, and B bursts. The purpose of the BCH is to allow the UT to gain coarse timing and frequency synchronization and to determine the best BS with which to communicate, both for initial acquisition and for handovers.

Two major considerations in the design of the BCH are the following.

1. The BCH compensates for the additional spatial processing gain of other channels (namely, CCH, TCH and RACH, to be defined and described later in this section) that have increased range and significantly less network interference due to adaptive antenna processing.
2. The BCH consumes a minimal amount of overhead so that it has a small impact on total base station throughput.

These design considerations lead to a BCH with few information bits.

4.2 CCH

The Configuration CHannel (CCH) serves two primary purposes.

1. The CCH is used as a fine adjustment mechanism for timing synchronization, e.g., during initial network acquisition and handovers.
2. The CCH is used to inform the UT of key BS and network parameters required for the UT to register with a BS (see Section 6).

There are only two messages carried by CCH. On the uplink, the Configuration Request (CR) message includes a field indicating the power of the transmitted CR burst to aid in uplink power control. On the downlink, the Configuration Message (CM) informs the UT of several key configuration parameters of the base station.

4.3 PCH

The Paging CHannel (PCH) is a downlink-only channel used to tell a UT to access the BS. It can be sent simultaneously with RACH and TCH on a given timeslot/frequency pair using spatial processing. Like BCH, PCH employs low-rate coding to compensate for the increased directivity of transmissions for other channels (namely, TCH and RACH) that results from the adaptive antenna processing. Therefore, the PCH conveys a small number of information bits. A page identifier (PID) is contained in each paging burst to communicate with a specific UT.

4.4 RACH

The Random Access CHannel (RACH) is used by the UT to gain access to a BS. It can be sent simultaneously with PCH and TCH on a given carrier-timeslot pair using spatial processing. Multiple messages are carried over this channel. The Request Access (RA) message is sent by the UT in the uplink, and contains a registration identifier (RID) that identifies a network session and indicates the transmit power of the burst containing the message. The Access Assignment (AA) message is sent by the base station in response to an RA message. The AA message is used in the downlink to grant a user terminal a TCH stream (see Section 4.5 that explains the concept of streams). The AA message contains several pieces of information, including the following.

- Modulation and coding information for the initial TCH burst(s) that follow
- Conventional channel (i.e., carrier-timeslot pair) assignment of the TCH stream
- Spatial training sequence (see section 6) assignment of the TCH stream
- Timing and power correction parameters

Figure 1 shows the Standard Downlink burst used for RACH, TCH, downlink CCH, and FACCH. The Standard Uplink burst is structured similarly.

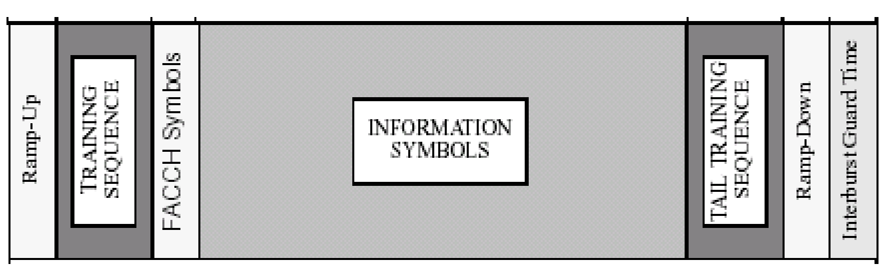

Figure 1 Standard Downlink burst structure

4.5 TCH

The Traffic CHannel (TCH) is used to transport both end-user and control traffic data. The RACH initiates a TCH stream. A TCH stream is a series of TCH frames used by a single user terminal and is the basic mechanism used to convey user and control data. TCH streams are created and closed in response to the bandwidth needs of each UT.

4.6 FACCH

The Fast Associated Control CHannel (FACCH) is a logical channel associated with RACH and TCH. It carries power control and link adaptation information. The FACCH has its own modulation and coding (Walsh-Hadamard) and is recoverable at low SINR. The FACCH enables fast link adaptation since it contains real time updates of the remaining available transmitter power and the modulation class of the TCH bursts that are being sent.

5 Frames and Timeslots

All uplink and downlink transmissions are scheduled on short time-intervals (timeslots) at a specified carrier frequency with a constant baud rate of 500 kSymbols/sec. Slots are paired (uplink and downlink) and grouped by the duplex period to define a frame. A transmission within a timeslot is called a burst.

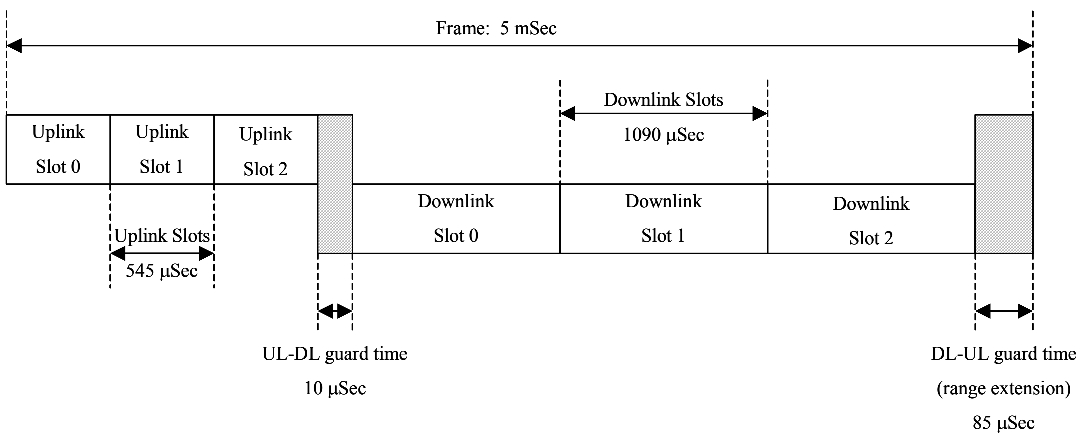

Figure 2 TDD/TDMA frame structure

The proposed TDD/TDMA frame structure is shown in Figure 2. This frame is designed for deployment in a narrow frequency channelization (625 kHz) with a constant baud rate (2 µs/symbol) across the frame. This specification has several advantages.

- Ordering uplink slots prior to downlink slots facilitates the implementation of spatial filters for adaptive antenna arrays in the BS.
- Narrow carrier bandwidth simplifies equalization, channel estimation, and network deployment in the available TDD spectrum.
- Narrow frequency channelization reduces access latency by providing many access channels

The logical channels defined in Section 4 are mapped to physical channels within the frame structure of Figure 2.

Figure 2 shows a range extension period of 85 μs, corresponding to a range of 12.7 km, suitable for metropolitan area coverage of MBWA as described in the 802.20 PAR. If inter-burst guard times in the air interface are exploited, the effective range extension period becomes 100 μs, corresponding to a maximum range in excess of 15 km. The range extension is obtained with less than 2% overhead of the frame period, and its cost is more than offset by the TDD and adaptive antenna benefits that it enables.

All TDD networks require close synchronization among all the BSs in the network. Any time reference with a stability of ±1 symbol period and with network-wide availability can be used for inter-cell synchronization of base stations. For example, the Global Positioning System (GPS) has the required stability and low-cost GPS receivers are available. In contrast, the UTs derive their timing reference from the BSs. A single carrier and timeslot pair is reserved network-wide for the broadcast superframe structure of Figure 3. The superframe is synchronized across *all* BSs in the network.

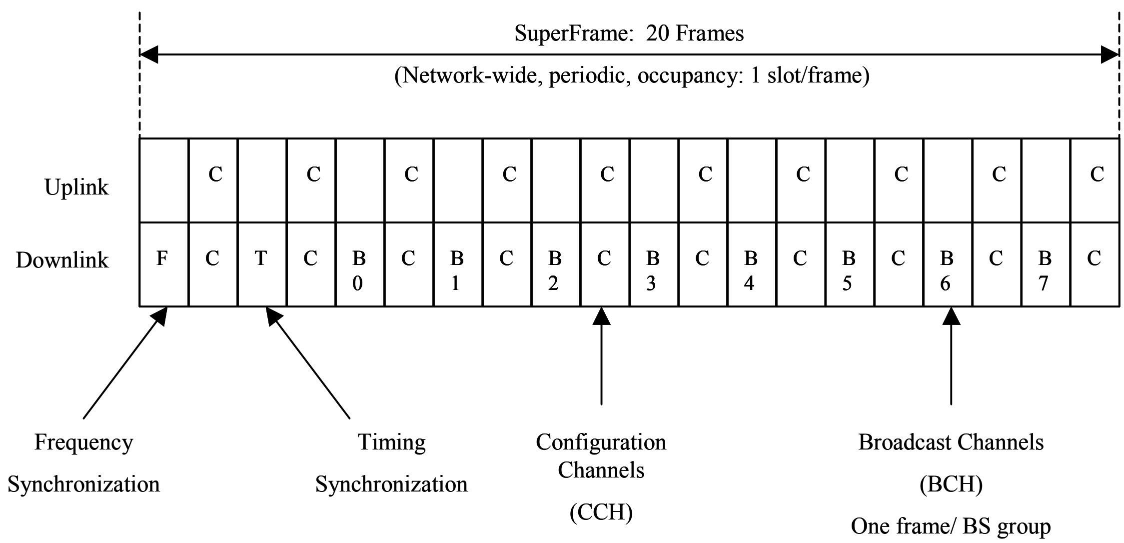

Figure 3 Superframe structure

The superframe begins with a downlink burst (F-type in Figure 3) designed to facilitate frequency-offset estimation between the UT local oscillator and the BS frequency reference. Similarly, a T-type burst is dedicated to frame time estimation. The UT can detect all BSs in its vicinity using the same BCH carrier and rank them according to the quality of their channel to the UT. The downlink slots labeled B0 to B7 in Figure 3 are dedicated to each of the pre-assigned *groups* of BSs. For example, only BS belonging to group 5 would send a downlink burst in the position labeled B5. The group-specific downlink slot is employed by all BSs in that group to transmit their BCHs. Acquisition of the BCH from within a group of base stations works best if interference from other base stations in the same group is minimized. At least seven base station groups are required to ensure that only one BS from the first tier transmits during its group-assigned slot in the BCH superframe. The remaining slots labeled “C” are paired uplink/downlink bursts and serve as the CCH.

6 Multiple Access

The overall channel bandwidth for a given system is divided into regularly spaced carriers. Time is slotted using the TDD frame structure. These time and frequency divisions define the set of conventional channels – a conventional channel is a carrier and uplink and downlink timeslot pair. The basic physical resource in the system is a spatial channel, which consists of a carrier, an uplink and downlink timeslot pair, and a spatial channel index. Multiple antennas and adaptive antenna processing make it possible to support multiple spatial channels simultaneously on the same conventional channel. Adaptive antenna processing permits all conventional channels, with the exception of the BCH / CCH, to be used simultaneously for RACH, TCH, and PCH, yielding high spectral efficiency and versatility. With close cooperation between adaptive antenna array processing at the BS and the higher-layer protocol stack, both PCH and RACH can be implemented without significantly penalizing the traffic capacity of the cell.

UTs exchange data with the BS on TCH streams (see Section 4.5). Streams may persist for only a few frames or for up to many seconds, depending on both individual and aggregate traffic conditions. Access requests and grants for streams are made on the RACH. The BS can prompt the UT to open a stream using the PCH. The BS can aggregate additional streams for particular users to increase their throughput or decrease their packet latency. Finally, the BS can break streams to make room for other users. These basic mechanisms – paging, stream aggregation, and stream breaking – are combined in the BS scheduler.

The UT establishes an association with the BS via a registration exchange, which takes place on an initial stream after UT power-up or during handover to a new BS. Registration is used to exchange terminal (BS and UT) capabilities, authenticate terminals, establish security, and to set protocol parameters. Once the UT has registered, the UT can request traffic streams and consume the air-interface bandwidth needed for its traffic.

7 QoS

This proposal supports QoS, with QoS behaviors defined using common traffic engineering modeling elements, such as token buckets, meters, algorithmic droppers, shapers, etc. The proposal supports a standard DiffServ solution. Per-session QoS can be specified to the radio access network using standard DiffServ Code Points (DSCP’s). The Per Hop Behaviors (PHB’s) are defined by a standard DiffServ API.

The BS scheduler is in charge of enforcing the QoS requirements for the aggregate set of network sessions, as configured through the DiffServ API. The air-interface is highly versatile, providing the basic mechanisms used by the BS scheduler.

Using the basic stream mechanisms, the scheduler can enforce basic QoS behaviors, such as individual rate limits, priority, and soft resource partitioning between aggregate classes.

8 Modulation and coding

While the symbol rate (500 kSymbols/s) is constant for all slots in the frame definition of Figure 2, the modulation order is adaptable (separately in uplink and downlink) to both the quality of a user's channel and the current data rate requirements. The six modulation formats proposed are shown in Table 3.

Modulation class used	Logical channel
π/2-BPSK	Control CHannel (CCH) Random Access CHannel (RACH) Fast Associated Control CHannel (FACCH)
QPSK	Broadcast CHannel (BCH) Paging CHannel (PCH)
π/2-BPSK QPSK 8-PSK 12-QAM 16-QAM 24-QAM	Traffic CHannel (TCH) under control of the higher-layer link-adaptation protocol

Table 3 Modulation classes

This set of modulation classes is flexible, consisting of both constant-modulus and rectangular constellations. The UT is not required to implement all of the ModClasses. This facilitates low-cost, power efficient devices as well as providing for future addition of higher-order modulations to the protocol. Note that most of the logical channels are transmitted using the lowest-order modulation classes. These low-bandwidth channels, primarily used for air interface management, must be received correctly with high probability. The higher-order modulation classes are primarily intended for use by the traffic channels.

Information bits are subject to forward error control coding prior to transmission. The coding rates vary from 0.5 bits/symbol to 4 bits/symbol in the downlink and 0.5 bits/symbol to 3.5 bits/symbol in the uplink. The Forward Error Control (FEC) provides for these components.

- CRC-16 across the information portion of the payload.
- Error control codes including
    - Convolutional code
    - Block code
    - Shaping code

- Bit interleaving within a burst[5]
- Scrambling

The choice of codes is a function of the modulation class and includes provisions for puncturing and/or repeating portions of the block as required for rate matching.

9 Power Control and Link Adaptation

Power control and link adaptation control algorithms are present both in the uplink and downlink of the proposed air interface. The power control algorithm has open and closed loop controls. Both loops are controlled by the BSs, and hence the BS sends uplink power control and link adaptation commands in the downlink. To support centralized control by the BSs, the UTs need to report downlink signal quality (Signal to Interference plus Noise Ratio - SINR) back to the BSs. The UTs also needs to report the available transmit power (i.e. difference between the maximum available transmit power and the current transmit power) to the BSs in order to enable effective uplink link adaptation.

Power control and link adaptation messages are sent in every slot of every frame. Therefore the system is able to adapt to rapid changes in propagation channels and in the interference environment. Power control commands accommodate both fixed step commands to compensate for small changes in SINR (±1 dB) and variable step commands to compensate for large changes in SINR (up to ±8 dB). These commands are low bandwidth messages. The UT report (feedback on downlink signal quality) is present in every slot of every frame. The report is able to specify small (±1 dB) as well as large changes in the SINR (±8 dB). These reports are also low bandwidth messages.

Modulation and coding information is conveyed through FACCH. This channel carries information on the recommended modulation and coding class and the current modulation and coding used to construct the payload. This information is exchanged between the BS and the UT on a slot-by-slot basis.

10 Data Transport

User and certain control data are transported using TCH streams. TCH streams provide two data delivery mechanisms.

1. Unacknowledged Mode (UM) traffic that is not sent through ARQ.
2. Acknowledged Mode (AM) traffic that is sent through ARQ.

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[5] Bit interleaving is done within a burst for fading immunity. It is not done across bursts as that would introduce significant latency.

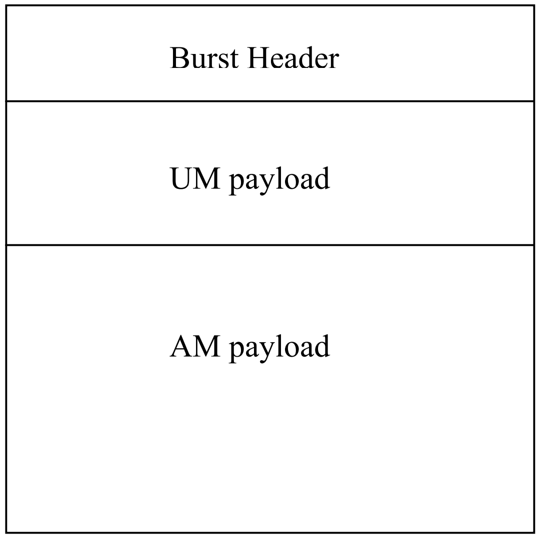


Figure 4 Burst Payload Format

UM and AM traffic are multiplexed on a burst-by-burst basis within a TCH stream as shown in Figure 4. In order to multiplex efficiently and flexibly, the UM messages form a prefix code. AM traffic is mostly end-user data, but it may also contain control messages that need to be sent reliably. AM traffic is sent reliably using an ARQ scheme. The following describes the attributes of the ARQ scheme.

1. The endpoints are in the L2 layer of the UT and BS, minimizing the retransmission latency.
2. The ARQ scheme is byte-oriented, which allows for flexible payload sizes that result from adaptive modulation and the AM/UM multiplexing scheme.
3. The acknowledgement scheme is cumulative, i.e., the acknowledgements report the next byte expected for contiguous reception.

In order to facilitate the ordered and reliable delivery of AM traffic over aggregated TCH streams, a set of Packet Data Conversion Layer (PDCL) algorithms is to be applied to the AM traffic flow. The set of PDCL algorithms is extensible. The following list contains the key PDCL algorithms.

1. L3 packet checksum. This is used to augment the L1 checksum that is applied to each TCH burst.
2. Packet sequencing and reordering. This algorithm allows the receive side to reorder packets that have been sent in parallel by multiple streams.
3. Packet Fragmentation. This algorithm fragments packets into smaller units in order to reduce latency when there are multiple streams open for a connection.

11 Support for adaptive antennas

In a frame (see Figure 2), uplink slots precede the downlink slots to provide current spatial training data for each downlink transmission. Each uplink slot is paired with a downlink slot. Pairing of uplink and downlink slots ensures that the uplink and downlink interference environments will be highly correlated. The duration between any paired uplink and downlink slot is small (1-2 ms) to prevent channel conditions from degrading the degree of channel reciprocity existing between the uplink and downlink slots and hence degrading the adaptive antennas' performance. Therefore, the frame duration is also small (5 ms). Carrier bandwidth is relatively narrow (625 KHz) to enable low complexity adaptive antenna algorithms.

On a given carrier-timeslot pair, each user is assigned a unique training sequence. Training sequences are designed for appropriately accurate estimation of the propagation channel. Each UT sharing a conventional channel via SDMA uses a unique training sequence from a selected set with good correlation properties. The cross correlation property between the training sequences is very low. The autocorrelation of the training sequences for the non-zero lags is very low, simplifying processing of the adjacent-cell interference.

The BCH is a heavily coded channel with low order modulation so that the link budget on the BCH matches that on the adaptive antenna enhanced TCH and RACH. Similarly, the PCH is heavily coded with low order modulation.

12 Air Interface Handover[6]

The air interface's make-before-break handover scheme is UT-directed. Each UT monitors the broadcast channels from surrounding BSs and ranks candidates based on signal power and other factors. A UT can perform these measurements as well as register with a candidate new serving BS while exchanging TCH data with its current serving BS. The handover for user data is make-before-break with the TCH data being redirected to the new serving BS after successful registration.

[6] Handover of an end-to-end IP session is the combined result of handover in the radio network from one cell to another with re-routing of the end-user's IP session to reflect the new serving cell. While IP networking, service and provisioning issues are beyond the scope of this document, one type of carriage currently supported by the air interface is PPP-encapsulated IP data between an IP Service Provider and an end-user device such as a laptop. PPP (cf. IETF RFC 1661, *et al*) is a low-overhead — one to two bytes per IP packet — tunneling protocol with the advantages of near-universal availability on IP devices, combined with universal deployment of equipment for PPP termination, provisioning, billing, rating and so forth in Service Provider networks. PPP also has the advantage of segregating IP sessions in the transport network, thereby allowing overlapping address spaces as typically used by corporate VPNs. One type of handover currently supported by the air interface is the lightweight Simple IP model employed by 3GPP2 (cf. 3GPP2 P.S0001-B, "Wireless IP Network Standard") for micro-mobility, complemented when necessary by Mobile IP (cf. IETF RFC 2002, *et al*), for example when handing over to a dissimilar access network such as 802.11.

13 Security

The proposed air interface provides a robust security infrastructure with air interface confidentiality and authentication. It provides seamless support of IP-centric network, transport and application layer security. The air interface security architecture is designed to overcome known problems in contemporary wireless systems.

13.1 Authentication

Authentication (for both the BS and UT) is be based on using digital certificates signed according to ISO/IEC 9796 standard using the RSA algorithm as the signature primitive. The digital certificates present information about the owner of the certificate and its elliptic curve public key. RSA modulus ranges from a minimum of 1024 bits to a maximum of 2048 bits. The authentication scheme does not require per authentication interaction with back-end servers. This simplifies and speeds up authentication and enables simple global roaming.

13.2 Shared Secret Agreement

Shared secret and air interface parameter exchange is performed using the public keys of the UT and the BS. The public key infrastructure is based on elliptic curve cryptography (using curves K-163 and K-233 in FIPS-186-2 standard). These public keys are certified using the digital certificates mentioned in Section 13.1.

During registration the UT and BS digital certificate transmissions, together with the public key encrypted shared secret and air interface transmissions, are interleaved to optimize air interface utilization.

Shared secret exchange capacity ranges from 163 bits to 466 bits depending on the needs of the bulk encryption algorithm.

13.3 Bulk Encryption

Bulk encryption is performed using a stream cipher such as RC4 initialized by a function of the shared secret and the temporal parameters of a stream to be encrypted (system may also support any block cipher that can operate in output feedback mode (OFB) or in cipher feedback mode (CFB)). The stream cipher supports a variable length shared secret key which is diffused properly prior to each stream start and shared secret refreshment is enforced by both the UT and the BS in order to circumvent errors in UT configuration settings.

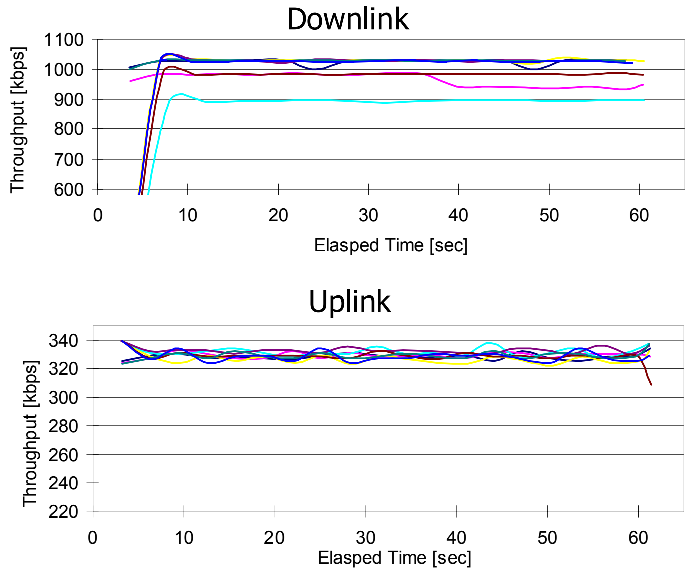
14 Performance

The proposed air interface has been implemented and tested. As an example of the performance testing conducted to date, the present section provides results regarding the performance of spatial channels and intra cell reuse.

Figure 5: Experimental configuration

This testing was performed at 2.3 GHz in a dense urban area, with eight co-located UTs located on a rooftop approximately 1 km distant from a BS equipped with an eight-element adaptive antenna array. Line-of-sight existed between the UTs and the BS, creating the most challenging spatial processing scenario due to the scarcity of path diversity and the closeness of the UTs. Figure 5 depicts the UT portion of the experimental configuration (the UT's are the boxes attached via white cables to the laptop computers).

In this instance, spatial processing performance was validated via sequential experiments. In the first experiment, eight carriers were employed, and simultaneous links were established between each of the eight UTs and the BS with nominal uplink and downlink user data rates of 330 kbps and 1 Mbps, respectively. In that configuration, each terminal continuously aggregated all of the time slots on its assigned carrier. Simultaneous data transfers were performed from a server upstream of the BS to the laptops, followed by simultaneous data transfers from each laptop to a server upstream of the BS. A commercial IP load generator was employed. Figure 6 depicts the time history of the uplink and downlink transfer rates for each UT. The average rates for each UT, following the startup transient period, are provided in the table to the right of the figure. This experiment, where each terminal is on a separate carrier, serves as a reference case.



Average Data Rate [kbps]

	Downlink	Uplink
UT#1	1,023	328
UT#2	964	329
UT#3	1,027	325
UT#4	892	331
UT#5	1,026	332
UT#7	982	328
UT#8	1,027	328
UT#6	1,025	328
Total	7,966	2,629

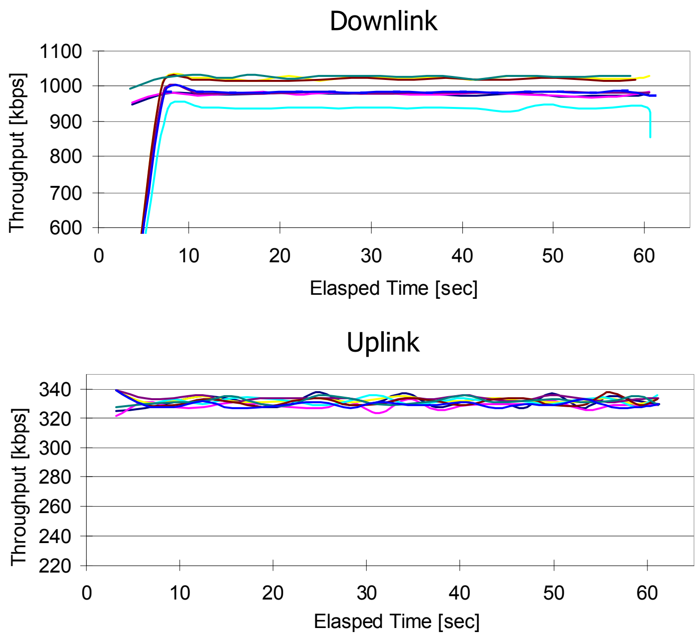
Figure 6: Control case

The system configuration for the second experiment was identical, except that only four conventional carriers were employed, each supporting two spatial channels. Equivalently, each of four carriers was reused twice within the cell to create eight virtual carriers. The system configuration and test setup were otherwise identical to those of the first experiment. Figure 7 depicts the results of the second experiment. The format of the figure is the same as that of Figure 6.

Combining the net uplink and downlink data rates from the table in Figure 7, and recalling that four carriers of the proposed air interface occupy 2.5 MHz, a spectral efficiency of

$$\frac{(7{,}909 + 2{,}649) \cdot 1024 \text{ b/s/sector}}{2.5 \text{ MHz}} = 4.3 \text{ b/s/Hz/sector}$$

may be calculated.



Average Data Rate [kbps]

	Downlink	Uplink
UT#1	975	331
UT#2	976	329
UT#3	1,020	332
UT#4	936	332
UT#5	979	333
UT#6	1,017	331
UT#7	1,025	332
UT#8	981	329
Total	7,909	2,649

Figure 7: Reuse 1/2 performance

15 Summary

Table 4 summarizes the key elements of the proposed TDD MBWA air interface.

Quantity	Value
Duplex Method	TDD
Multiple Access Method	FDMA/TDMA/SDMA
Access Scheme	Collision sense/avoidance, centrally scheduled
Carrier Spacing	625 kHz
Frame Period	5 ms
User Data Rate Asymmetry	3:1 down:up asymmetry at peak rates
Uplink Time Slots	3
Downlink Time Slots	3
Range	> 15 km
Symbol Rate	500 kbaud/sec
Pulse shaping	Root raised cosine
Excess channel bandwidth	25%
Modulation and coding	- Independent frame-by-frame selection of uplink and downlink constellation + coding. - 8 uplink constellation + coding classes - 9 downlink constellation + coding classes - Constant modulus and rectangular constellations
Power Control	Frame-by frame uplink and downlink open and closed loop
Fast ARQ	Yes
Carrier and timeslot aggregation	Yes
QoS	DiffServ policy specification, supporting rate limiting, priority, partitioning, etc.
Security	Mutual UT and BS authentication, encryption for privacy
Handover	UT directed, make-before-break
Resource Allocation	Dynamic, bandwidth on demand

Table 4 Summary of the basic elements of the proposed TDD MBWA air interface

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