<table>
<thead>
<tr>
<th><strong>Project</strong></th>
<th>IEEE 802.20 Working Group on Mobile Broadband Wireless Access <a href="http://grouper.ieee.org/groups/802/20/">http://grouper.ieee.org/groups/802/20/</a></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Title</strong></td>
<td>Basic Elements of a TDD MBWA Air Interface</td>
</tr>
<tr>
<td><strong>Date Submitted</strong></td>
<td>2003-03-12</td>
</tr>
</tbody>
</table>
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| **Re:** | MBWA Call for Contributions |
| **Abstract** | This contribution contains the same material as IEEE C802.20-03/14, formatted for presentation at the March 2003 802.20 meeting. |
| **Purpose** | This set of slides will be presented at the March 2003 802.20 meeting to explain the authors’ submission IEEE C802.20-03/14. |
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802.20 Service Vision

- High end-user data rates, 1+ Mbps
- High aggregate cell capacity, low net cost of delivery
- High spectral efficiency, operation in limited spectrum
- Mobile or portable use
- Reliable “last mile” link optimized for IP
- Manageable and predictable network: QoS, Security, ...
- Leverage existing IP networks, provisioning, billing, ...
- Standard IP devices, IP application transparency
802.20 Mission

- “Serve the PAR”
- PAR is MAC/PHY proxy for service vision

spectral efficiency (b/s/Hz/sector)

range (km)

802.20 target

existing wide-area mobile data systems

3
Proposal Overview

• **Broadband IP for the mobile environment**
  - robust adaptive modulation & coding, power control, ARQ
  - efficient messaging, in- and out-of-band control data
  - mobility/handover support
  - bandwidth on demand, QOS support for tiered services
  - authentication and privacy for security

• **Integral support for infrastructure adaptive antennas (AAs)**
  - $10\log_{10}M$ SNR improvement for higher range, data rates
  - interference cancellation, not averaging, for high spectral efficiency
  - spatial rake: reduced temporal equalizer complexity
  - no AAs at terminals to minimize cost, complexity, power
  - tight MAC/PHY coupling for efficient design
AA Implications for Air Interface

- Benefits highest with reciprocal up- and downlinks
  - TDD provides (nearly) reciprocal uplink and downlink
  - “uplink before downlink” emissions policy for spatial training

- Narrower (aggregate-able) carriers preferred
  - smaller numbers of interferers \(\Rightarrow\) better per-interferer suppression
  - spatial signature coherency bandwidth at, e.g., 2 GHz is \(<\ 1\ MHz\)

- Traffic and broadcast channels treated differently
  - only traffic channels benefit from full coherent gain of AAs
  - broadcast channels must be coded/lightweight for same link budget
Outline

- **Layered Architecture**
  - L1
    - frame and superframe structures
    - modulation and FEC
  - **L2 and Logical Channels**
    - logical channels, burst types
    - channel usage
  - L3
    - multiple access, resource allocation
    - security, QoS
- **Field Results**
- **Summary**
# Layered Air Interface Organization

<table>
<thead>
<tr>
<th>Layer</th>
<th>Functionality</th>
</tr>
</thead>
</table>
| L3    | Session management  
Resource management  
Mobility management  
Power control and link adaptation  
Authentication |
| L2    | Reliable transmission  
Logical to physical channel mapping  
Bulk encryption |
| L1    | Frame and burst structure  
Modulation and channel coding  
Timing advance |
Outline

• Layered Architecture
  • L1
    • frame and superframe structures
    • modulation and FEC
  • L2 and Logical Channels
    • logical channels, burst types
    • channel usage
  • L3
    • multiple access, resource allocation
    • security, QoS
• Field Results
• Summary
L1: Frame Structure

- **Common to all carriers in system**
- **85 µs turnaround time ⇒ 12.7 km range**
  - >15 km possible by exploiting burst ramp up/down times
L1: Synchronization

- Wide area TDD systems should be synchronized
  - else downlink/uplink overlap causes significant interference

- Variety of base station (BS) synchronization options
  - GPS, clocks derived from backhaul, ...

- User terminals (UTs) typically synchronized over the air
  - by synchronizing to BS frame structure

- Significant benefits for interference management
  - with MAC, enable downlink interference management (more later)
L1: Modulation and Coding

- Fixed 500 kHz symbol rate
- 25% excess bandwidth → 625 kHz channel raster
- Adaptive modulation and coding
  - circular and rectangular modulations: BPSK to 24 QAM
  - variable coding rates from 0.5 b/Symbol to 4 b/Symbol
- ModClass: modulation/coding combination
  - 9 downlink ModClasses, 8 uplink ModClasses
  - roughly 1.5 dB separation between each class for fixed FER
- Low-order, low-rate ModClasses balance broadcast link
- All ModClasses available for data, link permitting
L1: Constellations

- Only $\pi/2$-BPSK and QPSK support mandatory
  - enables low-cost, power efficient terminals

<table>
<thead>
<tr>
<th>Modulation Order</th>
<th>Logical Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi/2$-BPSK</td>
<td>CCH, RACH, FACCH</td>
</tr>
<tr>
<td>QPSK</td>
<td>BCH, PCH</td>
</tr>
<tr>
<td>$\pi/2$-BPSK</td>
<td>TCH</td>
</tr>
<tr>
<td>QPSK</td>
<td>(under control of link adaptation)</td>
</tr>
<tr>
<td>8-PSK</td>
<td></td>
</tr>
<tr>
<td>12-QAM</td>
<td></td>
</tr>
<tr>
<td>16-QAM</td>
<td></td>
</tr>
<tr>
<td>24-QAM</td>
<td></td>
</tr>
</tbody>
</table>
L1: Forward Error Control

- Convolutional, block and shaping channel codes
  - puncturing and/or repeating as required for rate matching
- Bit interleaving within a burst
  - but not across bursts, too much latency
- CRC-16 across information bits of the payload
L1: Review

- **TDD/TDMA/FDMA organization with 5 ms frames**
  - multiple resources permit granular allocation, low latency
  - TDD well matched to adaptive antennas, asymmetric data

- **625 kHz carriers, constant symbol rate**
  - low complexity processing
  - good spatial coherence properties

- **Synchronized network**
  - over-the-air UT synchronization, external BS synchronization
  - predictable inter- and intra-cell interference

- **Adaptive modulation and coding**
  - provide robust link, options for inexpensive terminals
  - link budget matching of directive, non-directive transmissions
Outline

• Layered Architecture
• L1
  • frame and superframe structures
  • modulation and FEC
• L2 and Logical Channels
  • logical channels, burst types
  • channel usage
• L3
  • multiple access, resource allocation
  • security, QoS
• Field Results
• Summary
## Logical Channel Types

<table>
<thead>
<tr>
<th>Name</th>
<th>Function</th>
<th>Uplink</th>
<th>Downlink</th>
<th>Directive</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCH</td>
<td>Cell broadcast and synchronization</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>CCH</td>
<td>Registration</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>PCH</td>
<td>Asynchronous downlink paging</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>RACH</td>
<td>Asynchronous access, assignment</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>FACCH</td>
<td>Link adaptation: ModClass, power</td>
<td></td>
<td>X</td>
<td>w/TCH</td>
</tr>
<tr>
<td>TCH</td>
<td>Traffic and associated messaging</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
### Logical Channel to Burst Mapping

<table>
<thead>
<tr>
<th>Burst Type</th>
<th>Symbol</th>
<th>Logical Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Downlink bursts:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency Synchronization</td>
<td>F</td>
<td>BCH</td>
</tr>
<tr>
<td>Timing Synchronization</td>
<td>T</td>
<td>BCH</td>
</tr>
<tr>
<td>Broadcast</td>
<td>B</td>
<td>BCH</td>
</tr>
<tr>
<td>Page</td>
<td>P</td>
<td>PCH</td>
</tr>
<tr>
<td>Standard Downlink</td>
<td>D</td>
<td>RACH, TCH, CCH, FACCH</td>
</tr>
<tr>
<td><strong>Uplink Bursts:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Configuration Request</td>
<td>C</td>
<td>CCH</td>
</tr>
<tr>
<td>Standard Uplink</td>
<td>U</td>
<td>RACH, TCH, FACCH</td>
</tr>
</tbody>
</table>

- BCH consists of a sequence of F, T and B bursts
- PCH consists of a single P burst
- TCH, RACH, FACCH flow over sequences of U and D bursts
Broadcast CHannel (BCH)

• Downlink-only

• Allows UT to
  • gain coarse timing and frequency synchronization
  • determine the best BS with which to communicate

• Consists of F, T, and B bursts

• Limited directivity, low spatial gain hence
  • low order modulation, heavy coding to balance link
  • limited information to reduce resource consumption

• Transmitted via BCH superframe
BCH Superframe Structure

- Generally, all slots in network available for all logical channels
- Single exception is slot used for broadcast superframe

```
<table>
<thead>
<tr>
<th>Uplink</th>
<th>C</th>
<th>C</th>
<th>C</th>
<th>C</th>
<th>C</th>
<th>C</th>
<th>C</th>
<th>C</th>
<th>C</th>
<th>C</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downlink</td>
<td>F</td>
<td>C</td>
<td>T</td>
<td>C</td>
<td>B 0</td>
<td>C</td>
<td>B 1</td>
<td>C</td>
<td>B 2</td>
<td>C</td>
<td>B 3</td>
</tr>
</tbody>
</table>
```

SuperFrame 20 Frames
(Network-wide, periodic, occupancy: 1 slot/frame)

Frequency Synchronization
Timing Synchronization
Configuration Channels (CCH)
Broadcast Channels (BCH)
One frame/ BS group
Configuration CHannel (CCH)

- **Uplink and downlink**
- **Two primary purposes**
  - UT fine timing synchronization and power control
  - informs UT of base station channel organization
- **Two messages**
  - Up: On the uplink, Configuration Request (CR)
    - including burst power to aid in uplink power control
  - Down: On the downlink, Configuration Message (CM)
    - including channel organization at the base station
- **Message exchange via BCH superframe**
Paging CHannel (PCH)

- Downlink-only
- Informs inactive UTs of pending downlink data
- Can be spatially mux’ed with downlink TCH
- Heavily coded to compensate for lack of spatial gain
- Compact message format to minimize overhead
Random Access CHannel (RACH)

- Uplink and downlink
- Used for registration, asynchronous access & assignment
- Can be spatially mux’ed with PCH and TCH
- Carries multiple messages
  - Request Access (RA) in the uplink
  - Access Assignment (AA) in the downlink
- AA message contains
  - initial modulation and coding information for TCH
  - conventional channel assignment for TCH
  - spatial training sequence assignment for TCH
  - timing adjustment and initial power settings
Traffic CHannel (TCH)

- Uplink and downlink
- Mixed user data and control information via tagged types
- User data exchanged over TCH “streams”
  - contiguous sequence of uplink and downlink U and D bursts
  - U and D bursts allocated in paired fashion
  - U and D pairing provides path for ACKs
  - U and D pairing provides spatial training for users and interferers
- TCH streams can be aggregated within and across carriers
- Stream allocation according to demand, QoS, load
Fast Associated Control CHandel (FACCH)

- Associated with RACH and TCH
- Carries power control, link adaptation information
- Provides real time updates of
  - Available TX power overhead
  - Modulation format (“ModClass”)
- Recoverable at low SINR
  - Low-order modulated
  - Walsh-Hadamard coded
Example: Standard Downlink Burst

- Used for RACH, TCH, Downlink CCH, and FACCH
- Training sequences for spatial and temporal processing
- Standard Uplink burst structured similarly
- B, T, F, C, P non-directive, hence different training organization
Logical Channel Example: Data Exchange

- “Uplink before downlink” whenever possible
- Resources consumed only when exchanging data
L2 and Logical Channel Review

- Three classes of logical channels
  - BCH: UT independent broadcast
  - CCH, PCH, RACH, FACCH: UT dependent control
  - TCH: UT dependent mixed control and data

- Mix of dedicated and common burst types

- Burst structure, message ordering maximize training

- All physical resources available for data and/or control
  - except for BCH carrier/timeslot pair
Outline

• Layered Architecture
• L1
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  • logical channels, burst types
  • channel usage
• L3
  • multiple access, resource allocation
  • security, QoS
• Field Results
• Summary
L3: Multiple Access

• Definition: resource allocation among users
• Conventional channel is (carrier, timeslot) pair
• Basic resource for air interface is a triple
  • (carrier, timeslot, spatial index)
  • a “spatial channel”
• Spatial channels permit sharing of conventional channels
  • e.g., conv. channel with two TCH’s; TCH, RACH and PCH; ...
• Requires time, frequency, power, space resource allocation
  • as joint or separable problems
L3: Registration

- An association established by a UT with a BS
  - at UT power-up
  - prior to handing over to a new serving cell
- Exchange of fundamental information
  - BS and UT capabilities and configuration
  - mutual authentication, encryption initialization
- Typically bound to an end-user IP session
- Required for exchange of end-user data
  - via TCH streams, sequences of TCH packets
  - via TCH aggregates across timeslots or carriers
L3: Data Transport

- Two data delivery modes within a TCH stream
  - Unacknowledged Mode (UM)
  - Acknowledged Mode (AM), using ARQ

- UM and AM mux-ed within a stream via tagged data types

- ARQ
  - endpoints in L2 – at BS and UT -- minimizing latency
  - byte-oriented to accommodate flexible payload sizes, encryption

- Delivery over aggregated streams requires special care
  - L3 packet checksum
  - Packet sequencing and reordering
  - Packet fragmentation
L3: Quality of Service (QoS)

- **DiffServ model for policy provisioning and propagation**
  - Per-session QoS specified using DiffServ Code Points (DSCP)
  - Per-Hop Behaviors (PHB) are defined by a standard DiffServ API

- **BS and intermediate node schedulers enforce policy**
  - subject to available resources
  - subject to link conditions

- **QoS behaviors include**
  - per-session rate limits, per-session priority
  - soft resource partitioning among flow aggregates
L3: Security

• **Design goals**
  - mutual authentication and privacy
  - efficiency (speed, economy) in associated messaging
  - IP-centric solution comprising proven elements

• **Authentication**
  - mutual authentication of the infrastructure and the UT
  - ISO/IEC 9796 certificate based with RSA signature primitive
  - no per authentication interaction with back-end servers
L3: Security

• **Shared secret exchange via UT and BS public keys**
  - elliptic curve cryptography based PKI
  - certified public keys exchanged during authentication phase
  - shared secret exchange at authentication phase and subsequently

• **Bulk encryption using a stream cipher**
  - most appropriate with flexible air interface blocks
  - Ex: RC4, block cipher operating in Output Feedback (OFB) mode or Cipher Feedback (CFB) mode
  - supports variable length shared secret key
  - shared secret refreshment enforced both by the UT and the BS
  - proper diffusion practices
L3: Power Control & Link Adaptation

- Open and closed loop power control for TCH streams
- BS controlled via UT SINR and remaining power reports
- Initial settings from RACH exchange preceding a stream
- Ongoing signaling using FACCH and TCH header fields
- Link adapted for, e.g., 1% FER
L3: Air Interface Handover

- UT monitors and ranks BCH of surrounding BSs
  - aided by BCH superframe structure

- UT-directed, make-before-break
  - user traffic transits old serving BS while registering with new candidate serving BS
  - End-user session then routed via new serving BS

- Independent of end-user IP layer handover
  - (see C802.20-03/14 for IP handover discussion)
L3: Review

- **Basic resource is spatial channel**
  - (carrier, timeslot, spatial index) triple
  - created by adaptive antenna processing, resource allocation

- **Fast ARQ for reliable link**
  - endpoints at BS and UT to minimize retransmission time
  - byte oriented for variable length packets

- **QoS support**
  - per-session DiffServ policy definition and propagation model
  - radio PHB’s include rate-limiting, priority, aggregate partitions

- **Security**
  - authentication and privacy
  - comprised of standards-based elements

- **Mobility support**
  - make-before-break radio handover
  - IP layer handover treated independently
Outline

- **Layered Architecture**
- **L1**
  - frame and superframe structures
  - modulation and FEC
- **L2 and Logical Channels**
  - logical channels, burst types
  - channel usage
- **L3**
  - multiple access, resource allocation
  - security, QoS
- **Field Results**
- **Summary**
Field Results

- Air interface has been implemented and tested
- Urban trial to assess reuse < 1 performance
- Most challenging case: colocated terminals, LOS
- Reuse of ½ at peak data rate
Experiment Description

- **Experiment 1 (control case)**
  - reuse = 1
  - link established to 8 UTs with 8 carriers (total 5 MHz)
  - nominal uplink/downlink rates of 330 kbps/1 Mbps
  - each UT continuously aggregating timeslots on one carrier

- **Experiment 2**
  - reuse = ½
  - 4 carriers, each reused twice within the sector
  - configuration otherwise identical to control case
  - total throughput essentially identical to control case
Base Case: 8 Terminals, 8 Carriers

Average Data Rate [kbps]

<table>
<thead>
<tr>
<th></th>
<th>Downlink</th>
<th>Uplink</th>
</tr>
</thead>
<tbody>
<tr>
<td>UT#1</td>
<td>1,023</td>
<td>328</td>
</tr>
<tr>
<td>UT#2</td>
<td>964</td>
<td>329</td>
</tr>
<tr>
<td>UT#3</td>
<td>1,027</td>
<td>325</td>
</tr>
<tr>
<td>UT#4</td>
<td>892</td>
<td>331</td>
</tr>
<tr>
<td>UT#5</td>
<td>1,026</td>
<td>332</td>
</tr>
<tr>
<td>UT#6</td>
<td>1,025</td>
<td>328</td>
</tr>
<tr>
<td>UT#7</td>
<td>982</td>
<td>328</td>
</tr>
<tr>
<td>UT#8</td>
<td>1,027</td>
<td>328</td>
</tr>
<tr>
<td>Total</td>
<td>7,966</td>
<td>2,629</td>
</tr>
</tbody>
</table>
Reuse 1/2: 8 Terminals, 4 Carriers

- **Data rates unchanged**

### Average Data Rate [kbps]

<table>
<thead>
<tr>
<th></th>
<th>Downlink</th>
<th>Uplink</th>
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<tbody>
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<td>UT#1</td>
<td>975</td>
<td>331</td>
</tr>
<tr>
<td>UT#2</td>
<td>976</td>
<td>329</td>
</tr>
<tr>
<td>UT#3</td>
<td>1,020</td>
<td>332</td>
</tr>
<tr>
<td>UT#4</td>
<td>936</td>
<td>332</td>
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<tr>
<td>UT#5</td>
<td>979</td>
<td>333</td>
</tr>
<tr>
<td>UT#6</td>
<td>1,017</td>
<td>331</td>
</tr>
<tr>
<td>UT#7</td>
<td>1,025</td>
<td>332</td>
</tr>
<tr>
<td>UT#8</td>
<td>981</td>
<td>329</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>7,909</td>
<td>2,649</td>
</tr>
</tbody>
</table>

- **10,558 kbps/2.5 MHz**
- **or 4.3 b/s/Hz/sector**
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Summary

• Adaptive antennas to shift capacity/coverage tradeoff
  • enable true reuse < 1, provide interference suppression not averaging
  • provide benefits in noise-limited case, too
  • require tight integration with all aspects of design

• Proven temporal, spectral processing techniques
  • adaptive modulation and coding
  • ARQ
  • power control

• IP service impacts considered at all levels in design
  • uplink/downlink (a)symmetry, data rates, latency, ...
  • fast ARQ transparent to end-user traffic
  • standards-based QoS model

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