Project	**IEEE 802.20 Working Group on Mobile Broadband Wireless Access** <**http://grouper.ieee.org/groups/802/20/**>
Title	**Basic Elements of a TDD MBWA Air Interface**
Date Submitted	**2003-03-12**
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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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Patent Policy	The contributor is familiar with IEEE patent policy, as outlined in Section 6.3 of the IEEE-SA Standards Board Operations Manual <http://standards.ieee.org/guides/opman/sect6.html#6.3> and in *Understanding Patent Issues During IEEE Standards Development* <http://standards.ieee.org/board/pat/guide.html>.

Basic Elements of a TDD MBWA Air Interface

802.20 Meeting #1
Dallas, TX USA

10-13 March 2003

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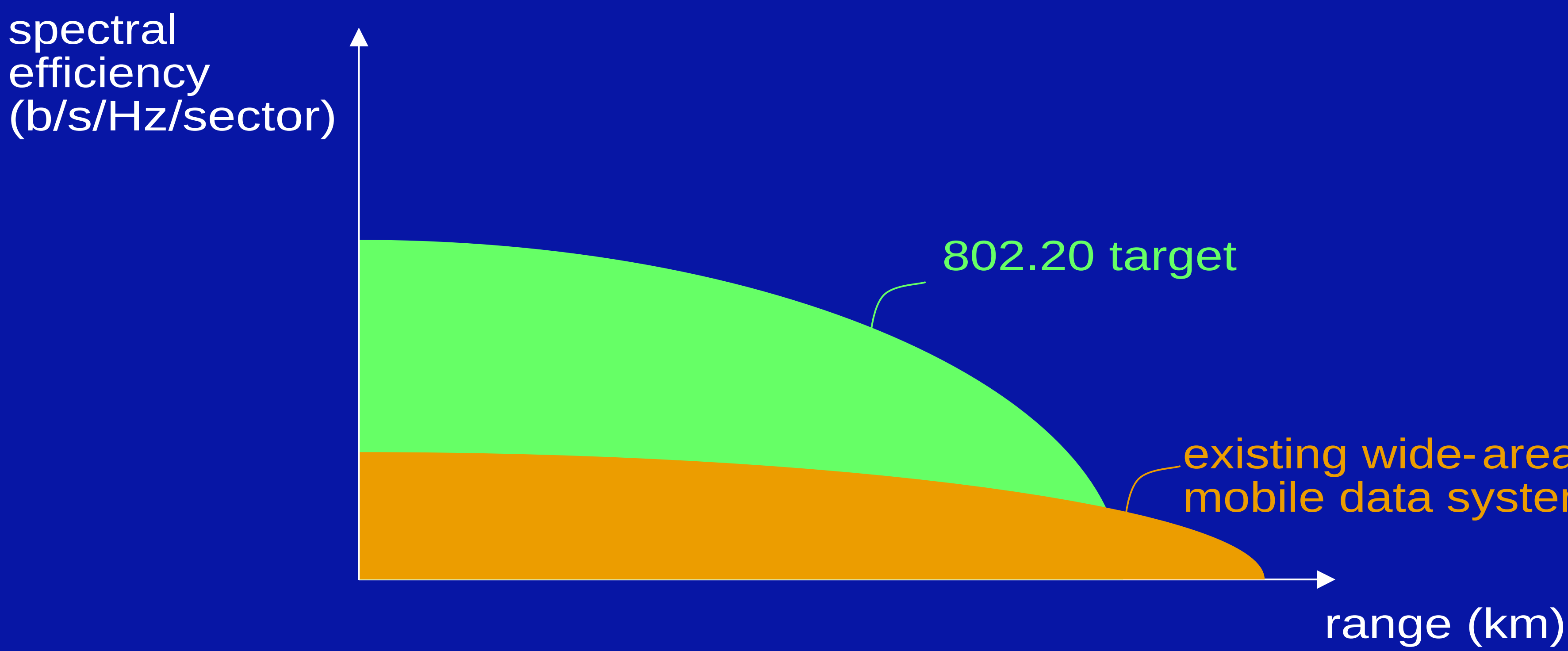
802.20 Service Vision

- 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



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

Layer	Functionality
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

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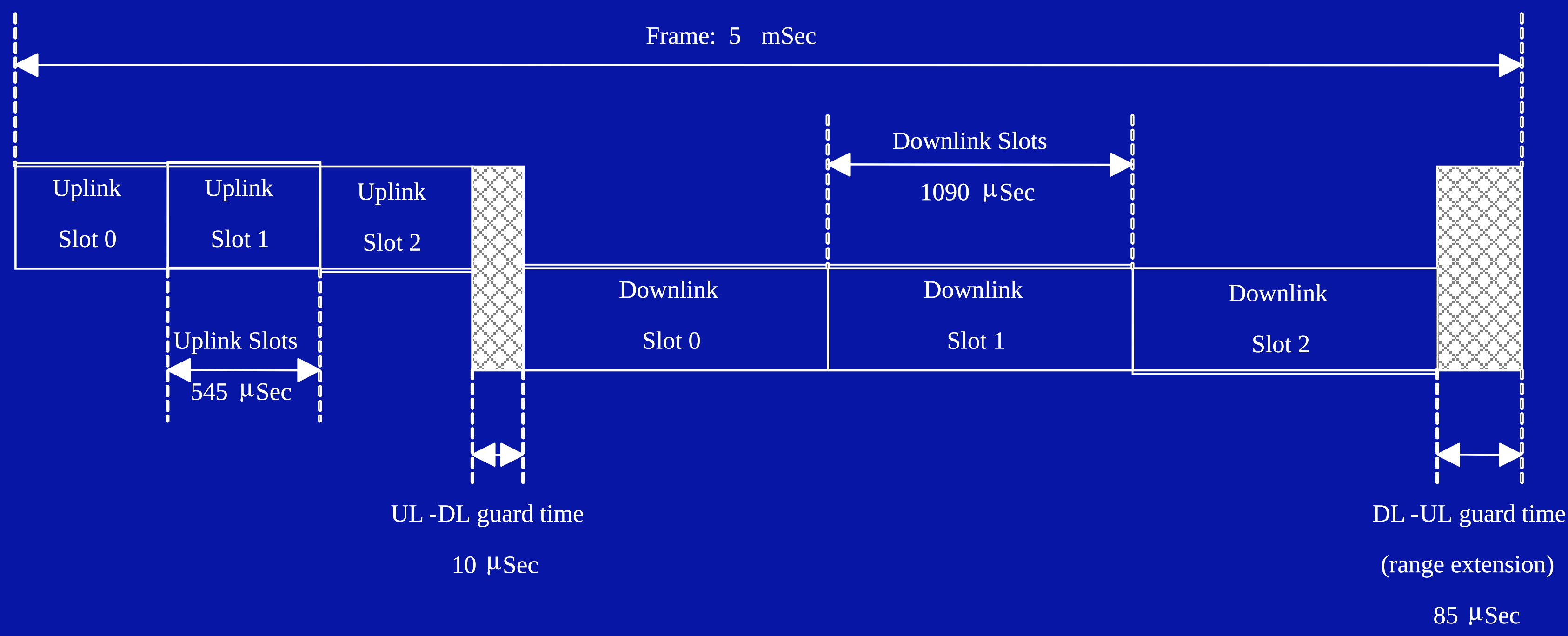
L1: Frame Structure



- **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 $\Rightarrow$ 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 π/2-BPSK and QPSK support mandatory**
  - enables low-cost, power efficient terminals

Modulation Order	**Logical Channel**
π/2-BPSK	**CCH, RACH, FACCH**
QPSK	**BCH, PCH**
π/2-BPSK **QPSK** **8-PSK** **12-QAM** **16-QAM** **24-QAM**	**TCH** **(under control of link adaptation)**

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

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Logical Channel Types

Name	Function	Uplink	Downlink	Directive
BCH	Cell broadcast and synchronization		X	
CCH	Registration	X	X	X
PCH	Asynchronous downlink paging		X	
RACH	Asynchronous access, assignment	X	X	X
FACCH	Link adaptation: ModClass, power	X	X	w/TCH
TCH	Traffic and associated messaging	X	X	X

Logical Channel to Burst Mapping

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

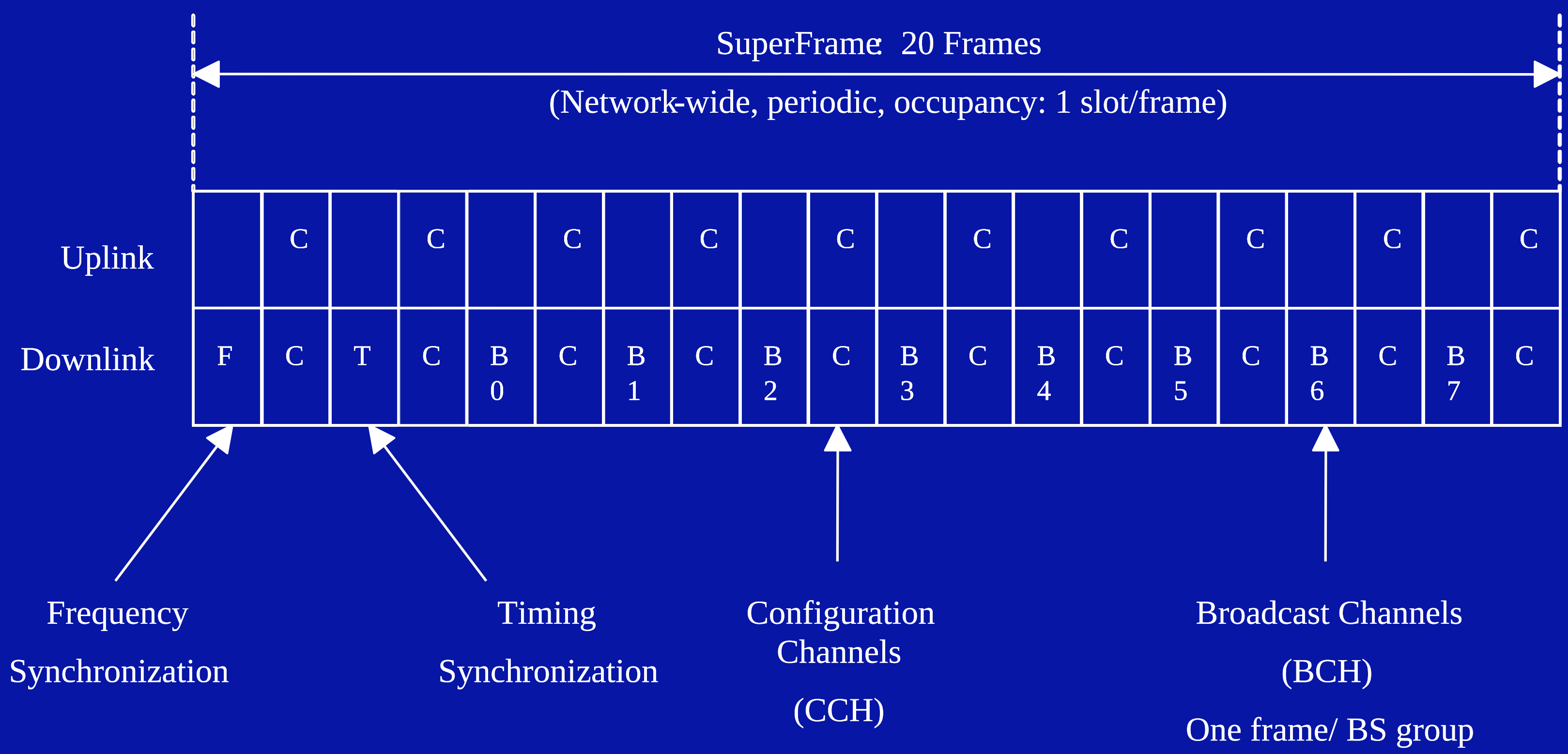
- **BCH consists of a sequence of F, T and B bursts**
- **PCH consists of a single P burst**
- **TCH, RACH, FACCH flow over sequences of U and D bursts**

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



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**
  - ↑ On the uplink, Configuration Request (CR)
    - including burst power to aid in uplink power control
  - ↓ 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

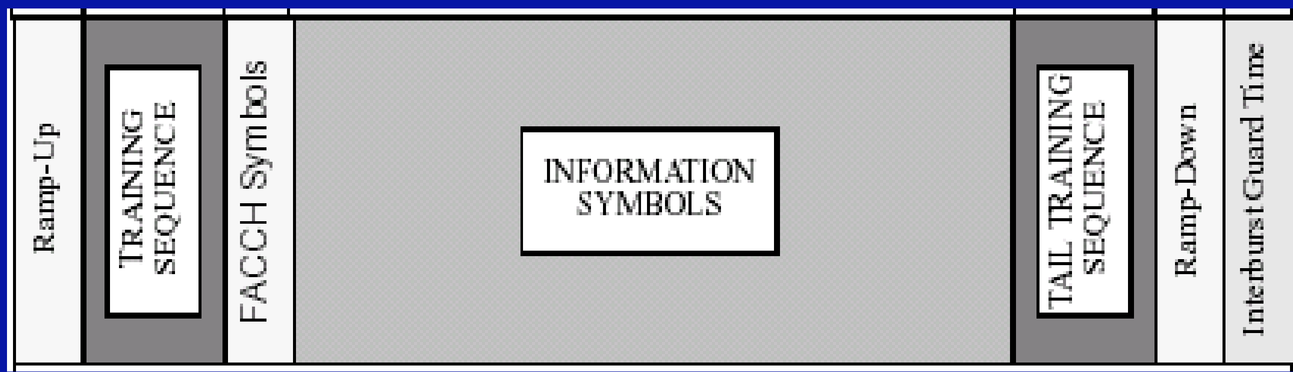
Traffic CHannel (TCH)

- **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 fasion
  - 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 CHannel (FACCH)

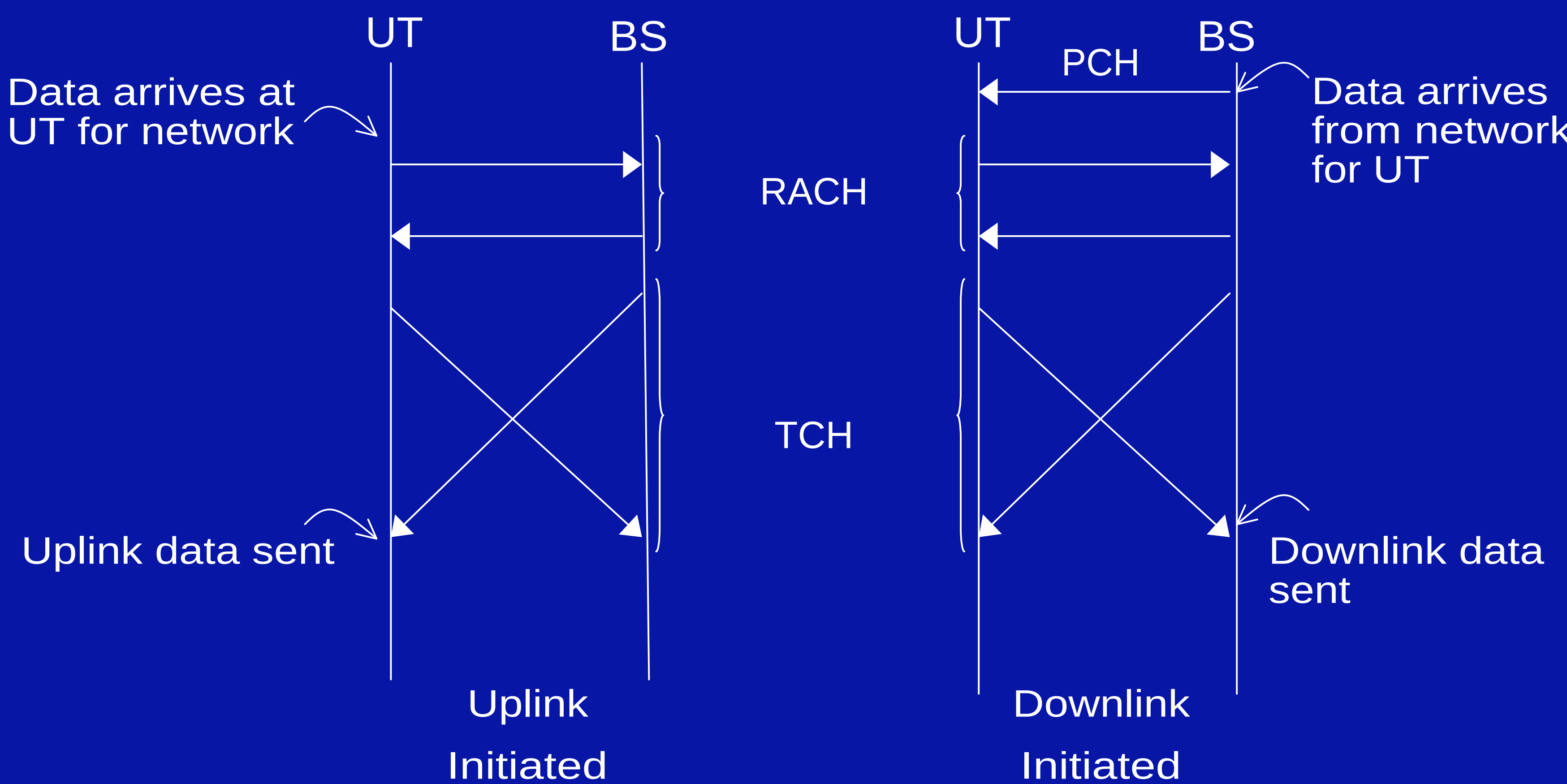
- **Associated with RACH and TCH**
- **Carries power control, link adaptation information**
- **Provides real time updates of**
  - Available TX power overhead
  - Modulation format (“ModClass”)
- **Recoverable at low SINR**
  - Low-order modulated
  - Walsh-Hadamard coded

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

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- **Layered Architecture**
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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**

Burst header	UM Payload	AM Payload

- **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 independenty

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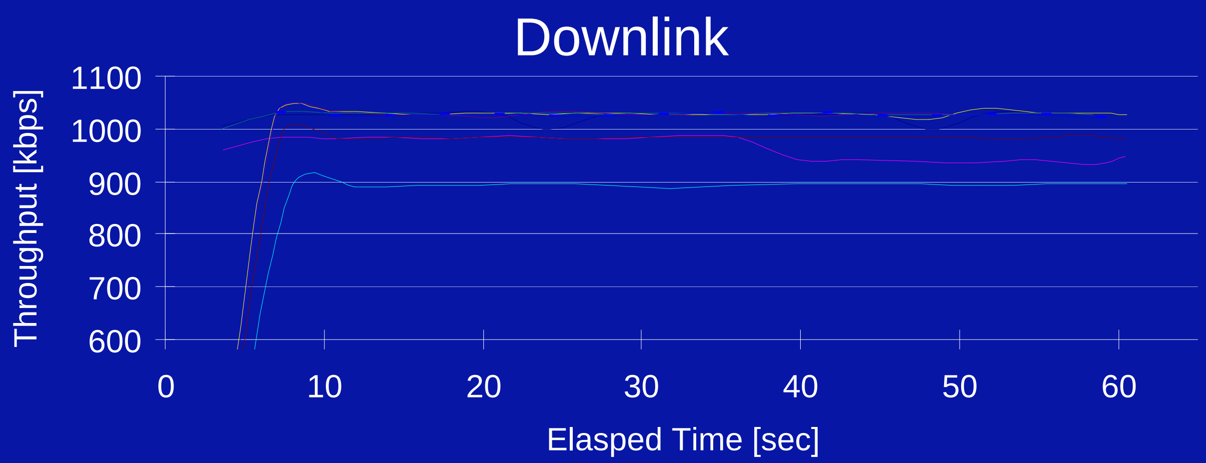
Field Results

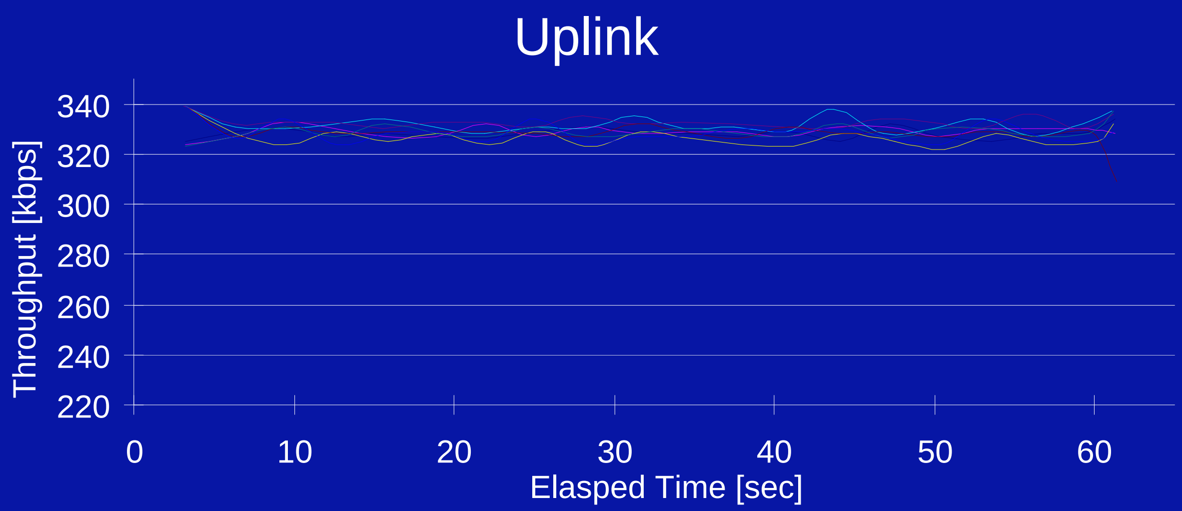
- Air interface has been implemented and tested
- Urban trial to assess reuse < 1 performance
- Most challenging case: colocated terminals, LOS
- Reuse of ½ at peak data rate

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

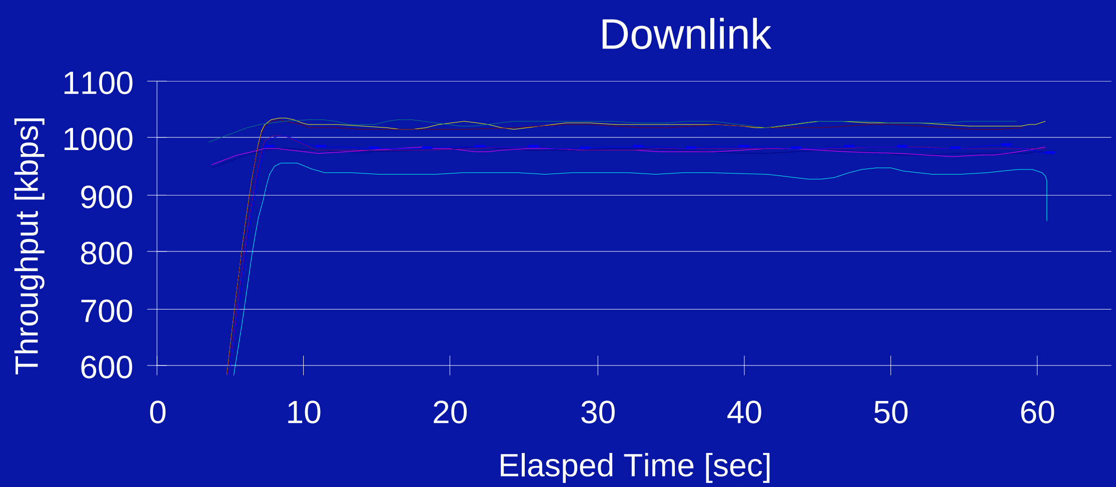


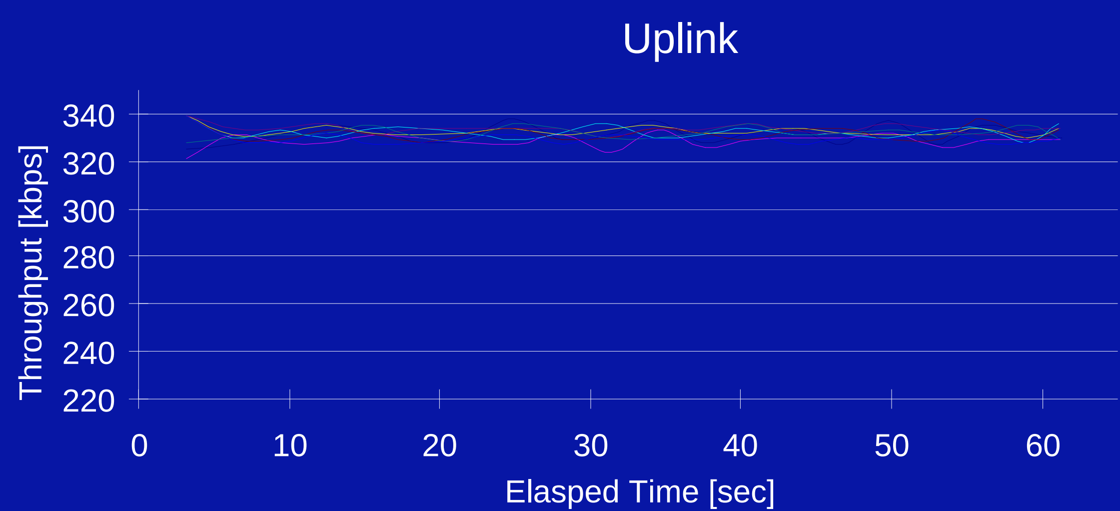


Average Data Rate [kbps]		
	Downlink	Uplink
UT#1	1,023	328
UT#2	964	329
UT#3	1,027	325
UT#4	892	331
UT#5	1,026	332
UT#7	982	328
UT#8	1,027	328
UT#6	1,025	328
Total	7,966	2,629

Reuse 1/2: 8 Terminals, 4 Carriers

- Data rates unchanged





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

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

Summary

Quantity	Value
Duplex Method	TDD
Multiple Access Method	FDMA/TDMA/SDMA
Access Scheme	Collision 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

Summary – Cont.

Quantity	Value
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