7

Potential Radio Interface Subsystems

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7.1 Advanced TDMA Mobile Access (ATDMA)

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This section provides a brief description of the advanced TDMA system which has been developed by the RACE ATDMA project.

This description is based on a submission made to COST231 by the RACE project consortium, which consists of the following companies; Siemens AG, Roke Manor Research, Alcatel Mobile Communication France, Alcatel Standard Eléctrica S.A., Universidad Politécnica de Cataluna, Télécom Paris, France Télécom CNET, ESG Elektronik-System-Gesellschaft GmbH, Fondazione Ugo Bordoni, The University of Strathclyde, DeTeMobil, Nokia Mobile Phones and Nokia Research Centre.

Further details of this system may be found in the published papers such as [1], and those at the RACE workshops [2, 3].

The submission to COST231 was made before the end of the project, and hence can not fully represent the final system design. For this the system description produced at the end of the project [4] should be consulted, which also describes the evaluation results obtained using the testbeds developed by the project.

7.1.1 Design Rationale

At the start of the project a set of design requirements were set. Where possible these followed the evolving vision of what UMTS and FPLMTS were in the respective standards bodies.

The ATDMA system is designed to provided:

A wider range of services in a wide range of environments.

Better quality and reliability.

Higher capacity.

Easier network planning & deployment.

To support all services it is thought that only a small set of bearers are needed. Based on this approach the following radio bearer services have been selected :

- Voice (high and normal quality)
- Data service with low delay (9.6 kb/s - 2 Mb/s at < 30 ms)
- Data services with long delay (9.6 kb/s - 2 Mb/s at < 300 ms)
- Data services with unconstrained delay (8 and 53 Byte cells)

The operating environments also place different constraints and requirements on the radio access system design, and so a single set of air interface parameters will undoubtedly not be optimal in all the situations. This consideration has lead to the project's concept of an adaptive air interface. Using this the system can be both more reliable, and more efficient.

The main forms of adaptation are:

Adaptation to Cell Types and associated propagation conditions

The different propagation conditions can not be optimally met with one radio interface with a fixed carrier spacing and so three basic cell types are required : pico, micro and macro cells. Each cell type is supported with a variant of the physical layer.

Adaptation to Interference

The error protection overheads and carrier slot assignments are dynamically varied to match the current conditions.

Adaptation to Source Activity

Physical channels are dynamically assigned to match the current requirements of each service.

7.1.2 Radio Access System Model

To correctly understand and capture the inter-relationships between these adaptation techniques and other radio access processes such as handover and admission control, the project has adopted a functional modelling approach [5].

The key features of the model are :

i a formal division between those functionalities involving the Transport of user and control messages over the air interface (modulation, error coding, etc.) where OSI layered techniques are appropriate, from those involving the Control of these transport functionalities (power control, packet access, handover, etc.) where functional modeling methods are more useful.

ii an abstract network architecture consisting of only three system elements: Mobile stations (MS), Base stations (BS) and the fixed Network.. This allows the radio access system to be specified independently of the final fixed network architecture.

The system is then modelled using the following logical groups:

Transport (TP). All radio and terrestrial transmission functions.

Link Controller (LC). Direct control of the transport group and co-ordination of the collection and pre-processing of all transport chain measurements.

radio Resource Allocator (RA). Responsible for the allocation of radio resource between different radio links and base stations.

Routing Controller (RC). Controlling the routing for the connection to the MS.

Traffic Controller (TC). Responsible for all call control functionalities.

Location Manager (LM). Responsible for the location management (registration, paging, etc.) of all attached mobile stations

Each of these Logical Groups will be distributed over some or all of the three basic network elements (see Figure 7.1.1).

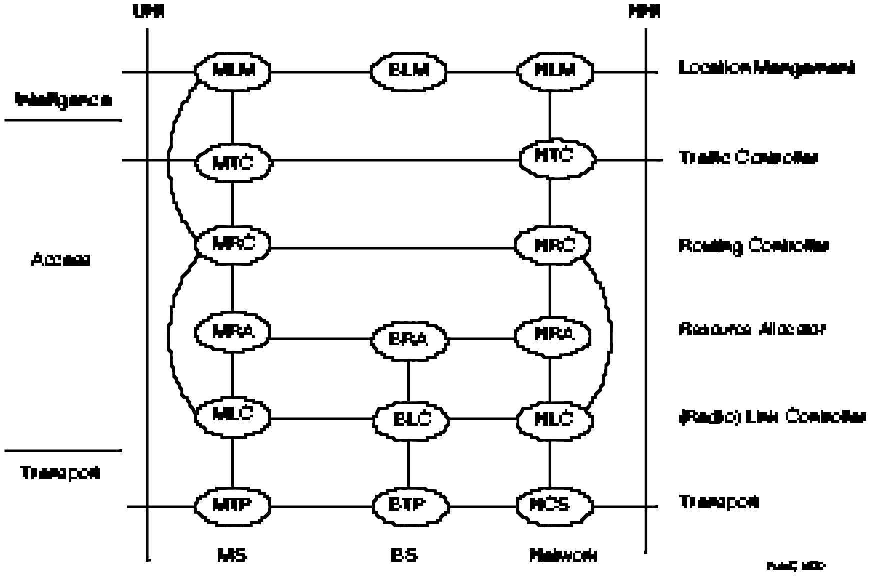

Figure 7.1.1 ATDMA Functional Model

In accordance with the OSI model the radio interfaces within the Transport group is defined by a three layer structure. with the upper network layer split into User and Control Planes:

Radio Physical Layer (RPL). Transport of TDMA bursts.

Radio Link Layer (RLL). Transport of logical channels.

UMTS Adaptation Layer (UAL). User plane of Network Layer. Adaptation of user traffic onto ATDMA radio bearer types

Signalling Network Layer (SNL). Control plane of Network Layer. Adaptation of Signalling messages (segmentation, rate adaptation) onto the ATDMA radio bearer types and support for content based routing to various locations in the fixed network. This layer is in parallel with the

UAL,

Figure 7.1.2 shows the layers within transport expanded, with other logical groups lumped together as the control applications.

This model is used in the following sections as the basis for describing the system.

7.1.3 Transport Technique

The transport chain for the air interface has been designed based on speech requirements and the desire to support an ISDN-B channel on a single carrier in macrocells.

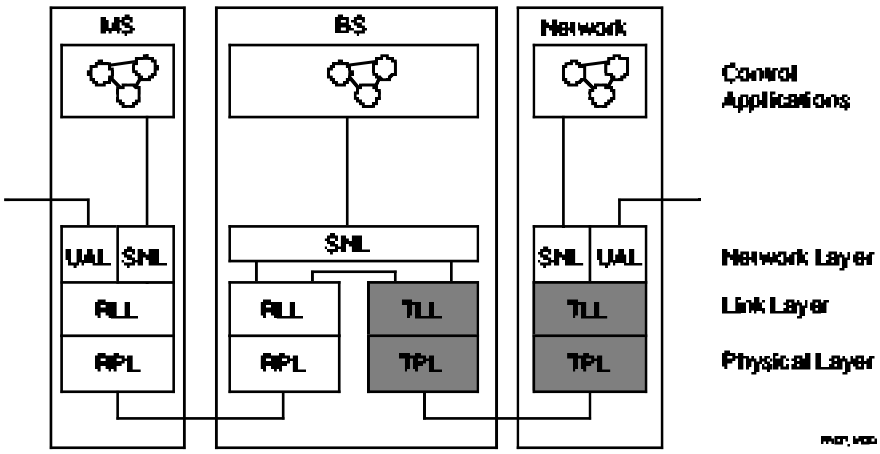

Figure 7.1.2 ATDMA Protocol Model

To support adaptation a set of modes are defined, each characterised by a certain configuration of the set {modulation, error control code, amount of radio resources} which guarantees a given performance for a given level of signal-to-noise + interference. The mode used will be selected by the link adaptation process which is described in the following section.

This overall radio transport chain is shown in figure 7.1.3 for a typical downlink traffic channel with the physical, link and UMTS adaptation layers indicated.

7.1.3.1 Radio Physical Layer

The physical layer provides the transport over the air interface of TDMA bursts (modulation, equalisation, frequency hopping, etc.). Key specifications for the ATDMA physical layer are given in table 7.1.1. Note that all channel spacings, carrier bitrates, slot duration periods can be generated from a common reference oscillator of 14.4 MHz

Burst structure

The principle influences behind the design of the burst and frames structures are the range and characteristics of the services to be supported, the constraints imposed by physical limitations and natural phenomena, and of the current state of the art of transport techniques and hardware implementation.

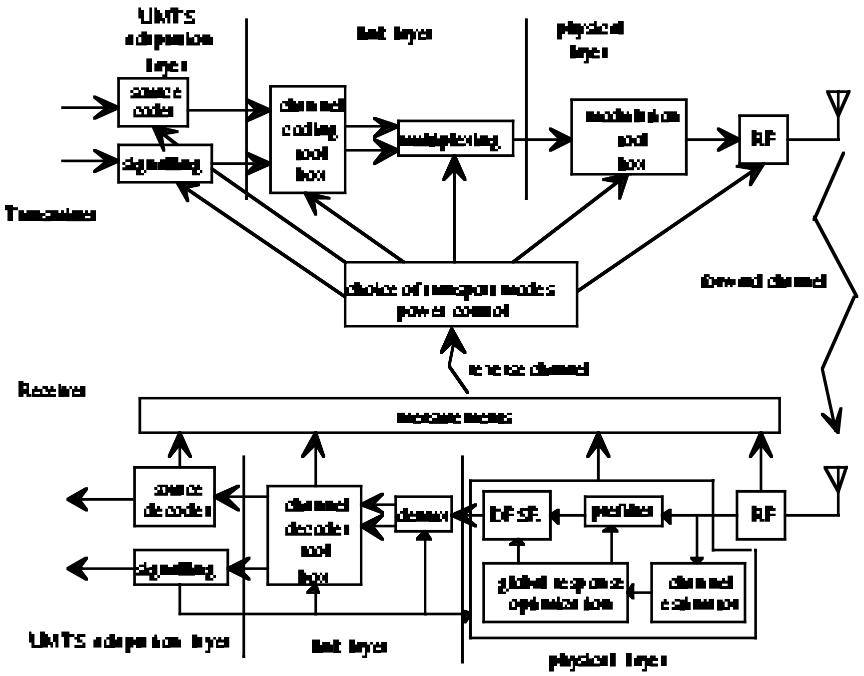

Figure 7.1.3 Example of an Adaptive transport chain for a downlink traffic channel

The format for the generic transmission burst is shown in figure 7.1.4.

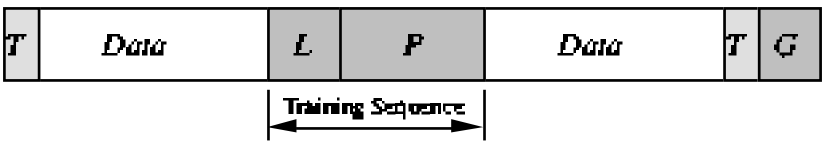

Figure 7.1.4 Generic burst structure

In addition when more than one burst per TDMA frame is assigned to the same bearer, e.g. for high data rate services, then these individual bursts can be concatenated into one and their contents redistributed to improve the use of radio resources.

Modulation

Binary offset QAM has been selected as the common basic modulation scheme for most cell types because of its spectrum efficiency, and because it is more robust to power amplifier non-linearalities than straight QAM. Higher level quaternary offset QAM is used to increase the carrier bit rate. In addition to these linear schemes, the GMSK modulation scheme is used to extended the maximum range of macrocells.

Cell type	*long*-Macro	*short* Macro	Micro	Pico
Modulation	GMSK	Binary Offset QAM		
Carrier Symbol Rates (kbaud)	360	450	1800	
Carrier Separation (kHz)	276.92		1107.69 = 4 x 276.92	
Slot Length (symbol)	120	125		
Training Sequence (symbol)	23	29 or 33		15
Payload (symbol)	76	72 or 76		96
Tail Bits (symbol)	8			6
Guard Time (symbol)	13	12		8
Frame Duration (ms)	5			
Slots per Frame	15	18	72	
Frames per multiframe	128			

Table 7.1.1 : Transport parameters for static adaptation

The complex envelope of Offset QAM may in general be expressed as:

$$u(t) = \sum_k \left[a_{2k} h(t - 2kT) + j a_{2k-1} h\left(t - (2k-1)T\right) \right]$$

where $1/T$ is the symbol rate, and a_k is the kth data symbol taking on values of ±1 for Binary Offset QAM and ±1 or ±3 for Quaternary Offset QAM.

In order to make Binary Offset QAM fully compatible with differential encoded GMSK (as in GSM), the data bits a_{2k} and a_{2k-1} are multiplied by $(-1)^k$ thus having alternate signs in both in-phase and quadrature components of the signal.

The shaping filter $h(t)$ is a filter having square root raised cosine spectrum:

$$|H(f)| = \begin{cases} 1 & 0 \le |f| < (1-\alpha)/4T \\ \cos\left[2T/4\alpha)(2\pi|f| - \pi(1-\alpha)/2T)\right] & (1-\alpha)/4T \le |f| < (1+\alpha)/4T \\ 0 & (1+\alpha)/4T \le |f| \end{cases}$$

Equalisation

It was decided in the ATDMA project not to undertake any theoretical studies on equalization but rather to exploit available results, particularly from RACE 1043. This resulted in two alternative equalization methods being selected, namely Decision Feedback Equalization (DFE) and Decision Feedback Sequence Estimation (DFSE) see [9].

7.1.3.2 Radio Link Layer

This layer is responsible for the transmission and reception of individual blocks over the air interface. The link layer is service type dependent with separate specifications for speech, low and long constrained delay data, delay constrained control channels and the short and large block unconstrained delay data bearer types.

The link layer for each of these bearer types when using binary offset QAM or GMSK modulation in the physical layer is defined below. When quaternary offset QAM modulation is used the base channel codes can be maintained however the number of interleaved bursts will be halved and the spectral efficiency doubled.

Speech

Speech coding has not been studied in detail inside the ATDMA project and so its associated error protection scheme has only been considered at a generic level.

It is assumed that the speech source coded blocks will use a conventional structure of FEC with inner convolutional coding and outer block coding.

A 13 kb/s gross rate is used which supports possible net bit rates ranging from 6.4 to 9.6 kb/s with different levels of redundancy added. Also a more robust mode, having a gross bit rate of 26 kb/s, is provided. These figures correspond well with the emerging standard for 8 kb/s speech coding in the ITU [10].

Constrained Delay Data

The low delay data service requires a delay < 30 ms and a 10^{-6} BER integrity in all cell types. For the long delay service the delay constraint is relaxed to 300ms (although increases over 200ms were found not to give further efficiency improvements).

A concatenated coding scheme has been chosen with a fixed 1/2 rate, constraint length 7, convolutional inner code and a variable rate outer Reed-Solomon code to provide a set of operation mode for link adaptation. Additional tail bits are appended to every input block to the encoder to fill up its memory and allow the corresponding trellis to end in a known state.

Codes have been defined for a range of different service bit rates. For example for the 64 kb/s service a set of 3 operating modes have been defined. These are shown in tables 7.1.2 and 7.1.3.

Mode number	Inner code rate	Outer code rate	Global rate	Bits per coded block	Half-bursts per interleaving period
1	1/2	1	1/2	1320	40
2	1/2	2/3	1/3	1980	60
3	1/2	1/2	1/4	2640	80

Table 7.12 : Summary of mode characteristics for 64□bit/s low delay Service.

Mode	Inner code rate	Outer code rate	Global rate	Bits per coded block	Data segments in interleaving period
1	1/2	1	1/2	3960	360
2	1/2	3/4	3/8	5544	504
3	1/2	1/2	1/4	7920	720

Table 7.13 : Summary of mode characteristics for 64□bit/s long delay Service

Short Block Unconstrained Delay Data

This bearer type is used for bi-directional signalling channels where the control applications can not directly support error detection but can tolerate a variable throughput. This is the assumed bearer for most fixed network-mobile signalling : call set-up, location registration, handover, etc.

The transmission scheme is based on a hybrid FEC/ARQ mechanism with a concatenated inner (4□;□3) parity code and outer RS (8□;□4□;□5) code over GF(2^3). A Service Data Unit (SDU) is transmitted over four bursts, hence containing 16x3x2□=□96 information bits. A field of 6 control bits protected by 6 CRC bits and 4 additional error correction bits to avoid false decoding is included. This leaves 80 bits for use by the Signalling Network Layer with the possibility to include a segmentation process to support longer messages.

Large Block Unconstrained Delay Data

A SDU of the size of an ATM (Asynchronous Transfer Mode) cell is used, i.e. 53 bytes. An extra byte is then added to this for carrying block numbering which has extra error protection.

A coding scheme has been selected which uses an inner (7,6,2) parity code and an outer RS (45,36) code. A cell is then mapped into two code words and carried by 10 burst. These can be transmitted over 10 TDMA frames, or sent more quickly when multiple slots are assigned.

When a cell is incorrectly received it will be re-transmitted by the control process. The receiver will then combine the two copies to allow a greater error correction capability. This allows a hybrid scheme to be implemented, but without the need for separate repeat numbering.

7.1.4 ATDMA Control System

While the design of the transport chain will contribute to the UMTS objective of improved spectrum efficiency and the support of a wide range of environments and services, most of the gain is achieved through the use of an active control system that continuously adapts the air interface to match the current conditions.

The following algorithms have been developed:

Quality based power control

Control of transmit power is used on both up and down links. The control algorithm uses link quality measurements on the link being controlled for longer term control, and measurements on the reverse link (as an estimate of path loss) for short term control. The range of short term power control is adjusted depending on the correlation between path loss in the two directions.

For services with multiple-slot allocations, each traffic slot is separately controlled.

Dynamic Link Adaptation

The operating mode of transport (coding, modulation, interleaving, etc.) for each of the delay constrained bearer services (speech and low and long constrained delay data) is adaptive to meet changing conditions. The link adaptation process selects the operating mode based on the need to ensure that service quality is being maintained with the minimum of assigned radio resources.

Two different link adaptation algorithms have been defined :

i *Short term link adaptation*. This process operates with an update period of between 0.5 and 5 seconds and bases its decision on the observed average channel quality of the assigned radio resource.

ii *Long term link adaptation*. This process is based on the observation that the distribution of C/I is dependent on the distance from the base station and so the transport operating mode is selected accordingly[8].

Large Block Unconstrained Delay Data

ARQ is used for traffic which require a high integrity, but can tolerate a variable delay (see section 1.1.3.2). The protocol used to control this uses both Positive and Negative Acknowledgments with a Positive Acknowledgment (ACK) for a particular block number representing an acknowledgment for all previous blocks (issued when the receiver successfully decodes a block that is in-sequence) while a Negative Acknowledgment (NAK) generates repeat transmissions of the selected blocks (issued when the receiver successfully decodes a block that is out of sequence - which implies that some blocks are missing). The use of a mixed acknowledgment type provide resilience to corrupted signaling.

The throughput and input buffer length are monitored and used to dynamically change the allocated resources to the service, likewise during periods of congestion the allocated resources can be reduced and re-assigned to higher priority services.

Dynamic channel assignment

A priority list based scheme is used to assign carriers and time slots. This is used each time a channel is assigned which could be at the start of a call, or for speech on every talk spurt.

This algorithm avoids the need for frequency planning, and provides some adaptation to current traffic distribution, but avoids the need for the base stations to communicate directly.

Handover and macro diversity

Since propagation conditions in some UMTS environments may be changing too rapidly for the mobile station to report measurements to the network and then wait for a handover decision, all normal handover trigger decisions are taken by the mobile and then signalled via either the old or new basestations.

Four separate handover criteria are included in the handover trigger stage: Link quality, Path loss, Range, and Power budget. This is necessary to give reliable handover in a system where slot allocation may be quickly changing, affecting interference, and link adaptation may maintain the bearer quality even when the mobile is in a non optimum cell.

Following handover trigger, the mobile selects the best candidate new base station. This step includes consideration of the new base station's current load (this is broadcast on the BCCH), path loss criteria and a desire to remain in the same cell type. This final criteria is designed to encourage slow moving mobiles to stay in microcells while keeping faster mobiles in macrocells.

An independent, demand assigned, Dedicated Control Channel (DCCH) is established to carry handover signaling. The existing traffic channels are not interrupted and so a true "seamless" handover is possible. An added advantage of the ATDMA handover process is that the release of the old traffic channels can be delayed until after the establishment of new traffic channels, and so a period of macro-diversity can be included.

Packet access

The previous sections may give the impression that each techniques has been designed separately. This is not the case, as many interaction must be considered to developed an overall system. Packet access is a technique which is utilised by several control algorithms to quickly assigned physical channels for TCH and DCCHs. It is described here in some detail to serve as an example of how the system model has been used to model the algorithms.

Capacity is allocated on demand using a technique called PRMA++ [6]. Like the original scheme proposed by Goodman [7], the PRMA++

protocol avoids wasting capacity during breaks in traffic source activity (during silence period in speech or for highly bursty data services), or the need to permanently allocate capacity for the maximum bit rate a call may need. It is also used to assign control channels for handover.

The main features of PRMA++ are:

- Time-slot allocation under BS control
- Separate physical channels for access control
- Physical channels allocated when requested, and kept until released (separate request not needed for each block sent)
- Common technique used for all traffic and dedicated control channels.

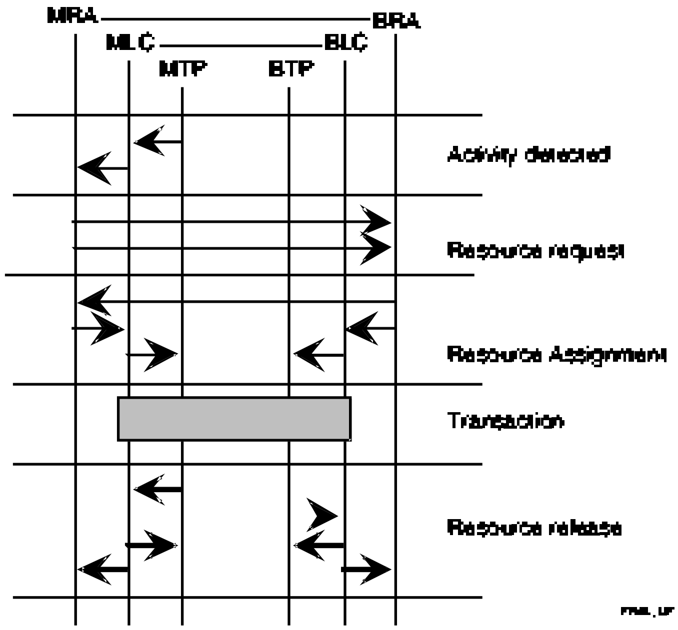

Figure 7.1.5 PRMA++ Uplink

The process for gaining access for uplink traffic is described below, and illustrated in figure 7.1.5.

1 Activity is detected by transport and the MLC informed. The MLC then asks the MRA to allocate capacity for the channel. Alternatively the request could originate in the MLC, for example, from the ARQ control algorithm.

2 The MRA will then make a request to the BRA for capacity using a random access control channel known as the R-slot with a message that states the Mobile Station and Logical channel Identifiers. The BRA will return the allocation on a paired acknowledgment channel, the "A-slot", with a message that states the Mobile Station

and Logical channel Identifiers and the allocated resources (in terms of carrier and slot numbers). This message also includes an Acknowledgment type flag which serves to indicate if the resource allocation has been queued (in case of congestion) or if the allocation message has been split over two or more bursts. If collisions occur on the R-slot then, following a time-out, the request from the Mobile is repeated.

3 The MRA and BRA will inform the LCs of the allocation

4 The traffic bearer becomes active and traffic is sent.

5 MTP detects the last item of data and the LCs then inform the RAs that the allocation can be released.

The process for the downlink is the same apart from the initial access procedure where contention access is not required, and the BS simply sends fast paging messages to allocate slots.

7.1.4.1 Resource Allocation

A key element in the ATDMA system which is used by all control techniques is the resource allocator. This base station centered entity is the key arbitrator in the ATDMA system and has the task of distributing the limited radio resources between various competing traffic sources (within the same MS and BS link), between different mobile stations (within the same cell) and between different base stations (within the same cluster and/or between cell types located in the same region).

The resource allocation functions can be divided into two broad classes : assignment of physical time-slots on a short term basis (channel assignment) and acceptance of a call into an individual cell (admission control).

7.1.5 Logical Channels

The ATDMA control channel structure is based on the CCITT classification [11], with refinements to accommodate the mixed use of both packet and circuit switched channels.

The control channels defined are:

Packet access common control channels (CCCHs)

A set of fast channels using single burst messages to provide the specialized common channels for PRMA++ access.

Leash Control Channel (LCCH)

A permanent control channel is used to keep control of each mobile that has set up a connection, even when no traffic is being carried. It supports a "watchdog" process (hence its name) and offers a low but guaranteed bandwidth. In a TDMA packet access scheme this channel is essential since it maintains time advance for Request slot bursts even after a long period of in-activity from the mobile.

Associated Control Channels (ACCH)

These control channels are strictly associated with each unidirectional bearer . A separate pair (forward and return) exists with each unidirectional component of a TCH or DCCH. The forward ACCH (ACCHf) is used for commands such as downlink mode changes. The return ACCH (ACCHr) carries mainly measurement information. This association with each undirectional bearer allow flexibility in supporting unbalanced or unidirectional traffic.

This association is illustrated in figure 7.1.6.

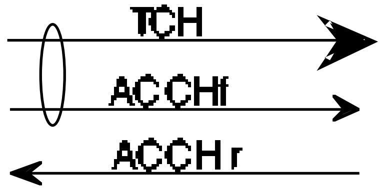

Figure 7.1.6 : Relationship between Traffic and Associated channels

7.1.6 Evaluation and Recommendations

The ATDMA system described has been extensively evaluated. This has provided results on the operation of each technique and the overall system, and led to a set of recommendations on the design of UMTS.

System Evaluation

The performance of the system has been evaluated by analysis, and using the projects simulation testbeds. The results are recorded in a publicly available deliverable [12].

The main conclusion is that the system fully meets the requirements which were set, and is hence a suitable candidate for the UMTS air interface. In particular it supports all the required service, does not require frequency planning, and can provide a high quality of service.

The evaluation of capacity is not easy to summarise, as the results depend greatly on the scenarios used for each test. For example link adaptation gives the largest improvements where higher coverage is required. However results generally show a significant improvement over existing system. [12] should be consulted for details.

Recommendations on UMTS Design

Based on the experience of ATDMA, recommendations for the design of UMTS have been made. The adoption of these would ensure that the lessons learned can be applied, even if UMTS is finally quite different from the ATDMA proposal. These recommendations are described in [4], and have also been submitted to ETSI [13]. These cover most aspects of UMTS including services, access network and air interface design.