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Re:	Call for contribution – October 29th, 1999 – PHY Task Group
Abstract	A PHY proposal addressing system requirements and based on fixed packet size is presented. TDD and FDD reconfigurability is supported with flexible frame structure and slot definition.
Purpose	Submitted for discussion and evaluation
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Release	
IEEE Patent Policy	

A PHYSICAL LAYER PROPOSAL ADDRESSING THE IEEE 802.16 SYSTEM REQUIREMENTS

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1. Overview

The following is a description of the Physical Layer proposed in the radio segment of the Point to Multipoint Broadband Wireless Access Systems compliant with the 802.16 standard.
The purpose of the Physical Layer is to support the Transmission Convergence adaptation function (TC Sublayer) and the Physical Medium Dependent modulation function (PMD Sublayer), suitable for the aforementioned Systems.
The proposed Physical Layer will work in conjunction with the MAC Layer proposal in the document “MAC Proposal addressing 802.16 System Requirements”.

The following Protocol Reference Model will be referenced to:

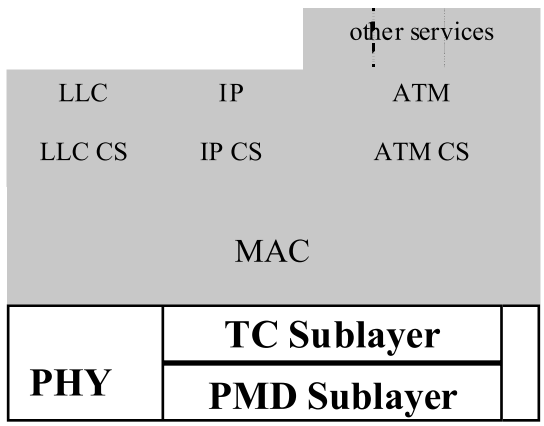

Figure 1 – The Protocol Reference Model

The proposed Physical Layer is divided into a TC Sublayer and a PMD Sublayer; the TC will interface with the MAC Layer.
The TC Sublayer is mainly involved in the generation and processing of data frames, mapping packets coming from the upper MAC layer to data Slots to be transmitted to the PMD layer for modulation, and vice versa. The TC Sublayer is also responsible for FEC overhead generation and error detection/correction.
The PMD Sublayer is responsible for modulation of data as received from the TC Sublayer, and vice versa.

2. General requirements

The present proposal is intended to fullfill the 802.16 System Requirements. Besides this, the following issues have been taken into consideration.

The prposal is based on the concept of allocation of capacity on a fixed time slot basis; the time slot being available for the transfer of packet or packetized information from the central Base Station (BS) towards the remote Subscriber Station (SS), and viceversa.
It is assumed that only the communication between the BS and the SS is possible; synchronization will be done based on the signal stream transmitted by the BS itself.

Due to the need of high exploitation of the radio resource, high efficiency modulation schemes will be proposed.

Due to the need to cope with the intrinsic variable nature of the propagation conditions in radio channel, adaptive modulation schemes will be proposed to satisfy the requirement for a high efficiency in bandwidth usage and for a high performance in terms of bit error rate/QoS.

It will be taken also into consideration the need to cope with different applications, with unpredictable variable capacity and with symmetric and asymmetric configurations. This will lead to an access scheme that must support a flexible dynamic allocation of the bandwidth, and both the Time Division Duplex (TDD) and the Frequency Division Duplex (FDD) modes of operation.

Assumed RF bandwidths are from 10 GHz up to 60 GHz. Multipaths propagation effects have to be taken into consideration for the lowest ones; while a high phase noise on RF oscillators is to be taken into consideration for the highest ones.

Since QoS parameters are required to be taken into consideration (better than 99.99% availability), high efficiency error correction codes will be proposed to optimize the performance.

3. Proposal Description

3.1. Duplex scheme and Access scheme

The proposal allows both a Frequency Division and a Time Division duplexing scheme. A TDM/TDMA access scheme is proposed, based on a Centralized Control MAC.

The communication between the Base Station and the Remote Subscriber Stations will be based on a TDM/TDMA scheme: both the downlink and uplink data streams will be a sequence of packets. Each packet will be allocated in a predetermined Time Slot. The time duration will be the same for all Slots, and the same for downlink and uplink.

In case of FDD, the downstream will be TDM continuous-mode; all packets are contiguous; the modulation process is continuous. The upstream will be TDMA burst-mode, being the upstream bursts frequency/phase synchronous with the downstream Slots.
In case of TDD, a time separation is required between downstream phase and upstream phase. Inside the downstream phase the transmission will be TDM continuous mode; inside the upstream phase the transmission will be TDMA burst-mode. The limit between the two phases will be flexible.

In both cases the association between the Time Slots and the related Remote Subscriber Stations will be determined by the Base Station, i.e. a centralized control MAC will be adopted. No need for a contention scheme is envisaged up to now, although a contention scheme is compatible with the overall Physical Layer architecture.

For a simple implementation, the Slot structure will be independent on the actual Bit Rate and adopted modulation scheme.

3.2. Slot Structure

Besides the transport of normal payload traffic, the TC shall support the relay of messages dedicated to internal operations such as MAC Bandwidth Request for silent Subscriber Stations and Admit operation. These messages will be handled with dedicated Slot formats.

Following is a description of the various Slot formats.

- Traffic Slot

The traffic Slot structure will be based on a MAC PDU field of 50/52 (t.b.d.) bytes, as required to be transported by the MAC Layer.
In the downstream direction each Slot will contain:

- a 50/52 bytes MAC PDU field, as relayed by the MAC processor, including the Payload field, the Connection Identifier field, and the MAC field
- a FEC field, for error correction in the MAC PDU field. Error detection capability will be also provided to allow for Slot discard in case of uncorrectable errors
- a Unique Word field, for Slot synchronization purposes

In the upstream direction only:

- a Preamble field is provided to allow for burst-to-burst synchronization of the Base Station receiver before payload start
- a 50/52 bytes MAC PDU field, as relayed by the MAC processor, including the Payload field, a Connection Identifier field, and the MAC field
- a FEC field, for error correction in the MAC PDU field. Error detection capability will be also provided to allow for Slot discard in case of uncorrectable errors
- a Guard field is provided to cope with the transmitter switch on/off time, imperfect Slot synchronization in the Base Station Receiver, and the variable latency of the transmission medium

Figure 2 below summarizes:

Figure 2 – Time Slot formats for Traffic Slots

In both cases the FEC field will provide error correction and detection for the entire MAC PDU field. As a temptative example, an 8 byte BCH FEC field is proposed, providing the following error correction capabilities in case of 52 bytes payload:

- t=7 N=543, R=63, Base = 9

The FEC redundancy shall be used also for error detection.

- “Admit” Slot

The Admit Slot structure will be based a Guard time and on an Admit Burst; the position of the Admit Burst inside the overall Admit Slot will allow the Base Station receiver to detect the distance of the Subscriber Station. The Burst will contain a Preamble, a short Information field of a few bytes, containing the identification code of the Subscriber Station, and a CRC field used for error detection.

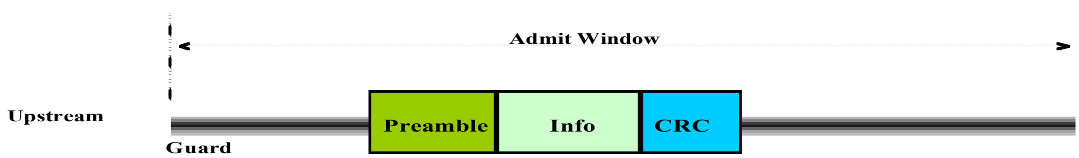

Figure 3 – Time Slot format for Admit Slot

- “Request of Bandwidth” Slot

The Slot will include several short Bursts, each one transmitted by a different Subscriber Station. The short Bursts will be separated by a Guard time. Each Burst will contain a Preamble, a short information field for capacity request, and a CRC field used for error detection.

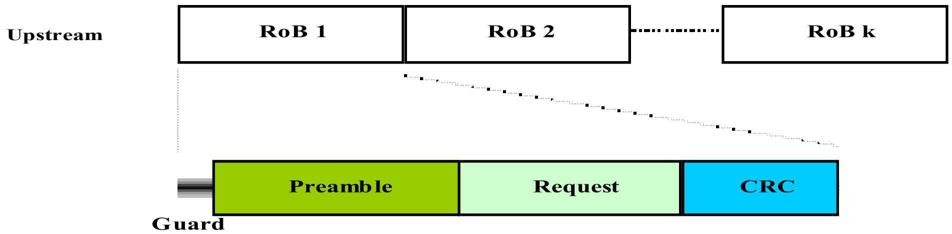

Figure 4 – Time Slot format for Admit Slot

As a first proposal the Preamble and Guard time are the same as for the traffic Slot, the Request field is 1 byte and the CRC is 1 Byte.

A contention scheme could be adopted for the Request of Bandwidth phase, allowing a reduction of the latency time for request delivering.

3.3. Scrambling

In order to ensure adequate spectrum randomization, both the downlink and uplink data shall be scrambled by means of a synchronous scrambler.
The scrambling will be applied to:

- normal length Slots - both downlink and uplink,
- short Slots (RoB) - uplink only

The scrambler sequence will be the shortened one obtained from the PRBS derived from the polynomial x^9+x^5+1, as drawn in Figure 5.
For normal length Slots the scrambling will affect the whole Slot except the Preamble.
The synchronization will be based on the Slot: loading the pattern “100000000” into the PRBS generator shall be operated at the start of each Slot; at the output of the PRBS generator the starting sequence (corresponding to the first two bytes) will be 00000000 10000100.

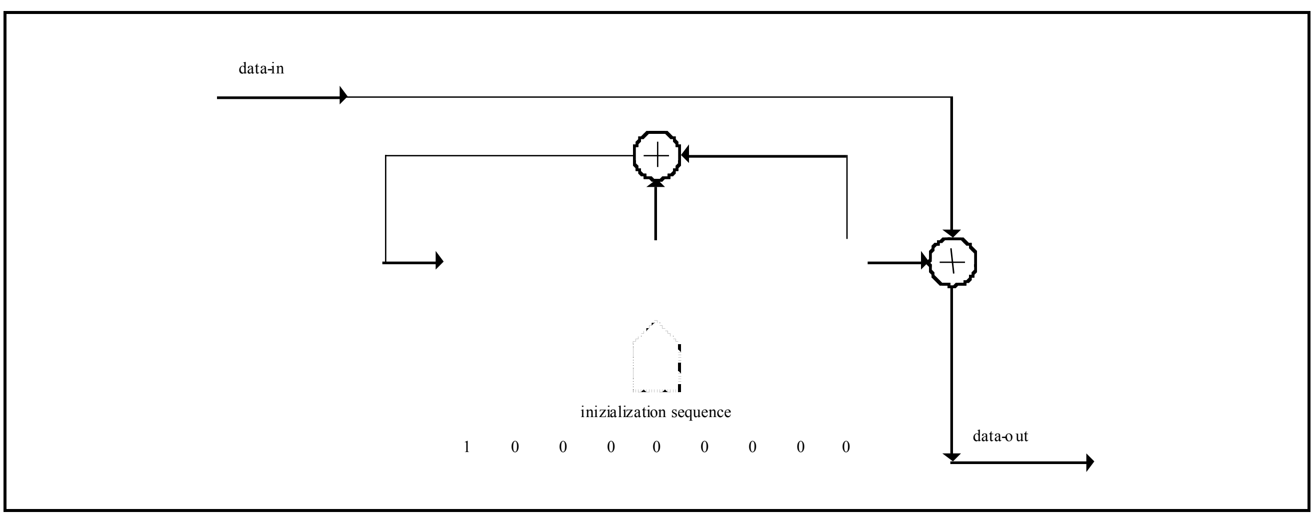

Figure 5 - Synchronous Scrambler

The same scrambling sequence will be used for the upstream short RoB Slots: the sequence generator will be initialized, as in the previous case, during the Preamble of the first Minislot; the generator will run continuously

during the whole Slot; the scrambling sequence will be applied only to the Information and CRC fields of the MiniBursts.
No scrambling will be applied to Admit Bursts.

3.4. Frame structure

A Frame is used for synchronization purposes.

The Frame structure will have a fixed time period, and will be filled with a continuous stream of Time Slots. The total number of Time Slots per Frame will depend on the actual Bit Rate/System Capacity chosen.

The actual Frame structure will depend on the chosen duplex scheme, on the traffic conditions and on the needed maintenance operations: “Request of Bandwidth” Slots are scheduled, upstream only, to allow for 64 Remote Station’s to be polled once every Frame. “Admit Slots” are scheduled only during the Admit phase, if needed. “PLOAM Slots” are scheduled, based on the controller request. When there is no need for Admit and PLOAM operations, all the Slots can be assigned to traffic. While Admit and PLOAM Slots are scheduled on request, the allocation of Request of Bandwidth Slots is proposed to be based on a fixed time period. A contention scheme could be adopted alternately.

In the following figures, some examples of Frame structure are proposed.

- **FDD Scheme**

The downstream will be a TDM continuous sequence of slots, dedicated to the payload traffic and to internal PLOAM.
The upstream, besides traffic and PLOAM slots, will allow the transport of information for the Admit procedure and for the Request of Bandwidth. The upstream Frame will be divided into a Traffic phase, an Admit phase (optional), and a Request of Bandwidth (RoB) phase.

See the following figure.

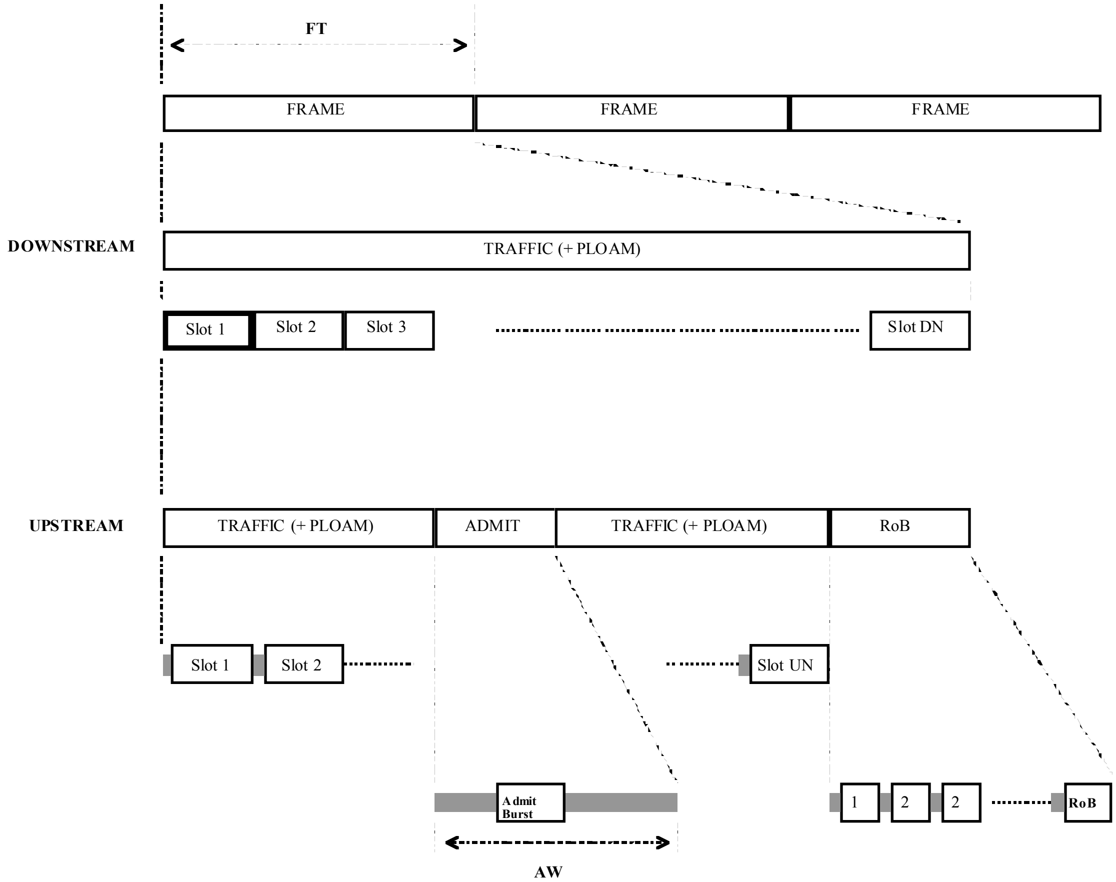

Figure 6 – Frame structure / FDD case

The identification of the downstream Frame is based on a predefined sequence of the UW in the downstream Slots.

Topic parameters are:

- FT Frame time duration
- DN total number of downstream Slots per Frame
- UN total number of useful upstream Slots per Frame
- BR number of Bandwidth Request Slots per Frame
- AW Admit Window time duration

- **TDD Scheme**

The Frame will be divided into a downstream phase and an upstream phase. The two phases are separated with an appropriate time guard.

In the downstream phase the Base Station will transmit a TDM continuous sequence of Slots, dedicated to the payload traffic and to internal PLOAM. The downstream phase will initiate with a Frame Preamble field.

During the upstream phase the Remote Stations will transmit in TDMA mode, based on permits received from the Base Stations. The upstream, besides payload traffic and PLOAM Slots, will allow the transport of information for the Admit procedure and for the Request of Bandwidth. The upstream phase will be divided into a Traffic phase, an Admit phase (optional), and a Request of Bandwidth (RoB) phase.
A PLOAM message will specify the structure of each Frame at the end of the downstream phase.

See the following figure.

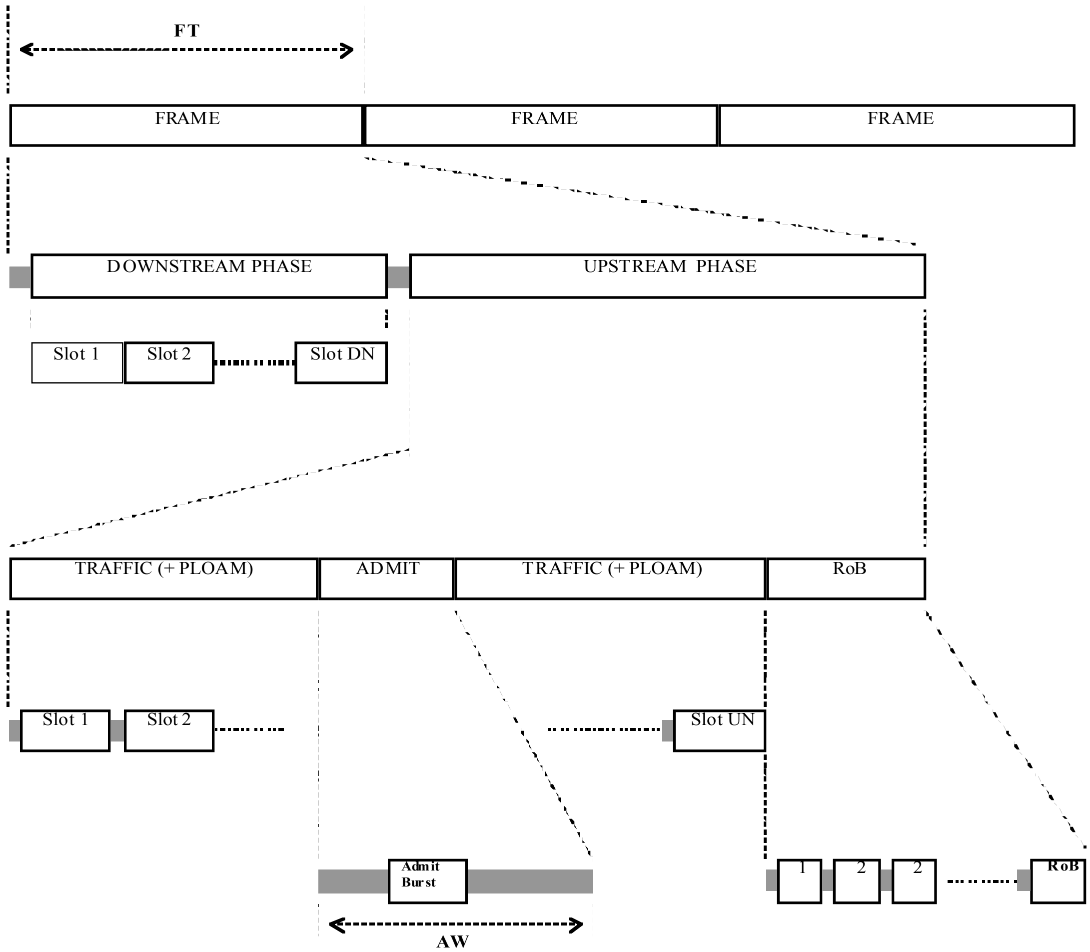

Figure 7 – Frame structure / TDD case

The identification of the Frame is based on the detection of the first of the downstream Slots. A Preamble will be needed.

Topic parameters are:

- FT Frame time duration
- DN total number of downstream Slots per Frame - variable
- UN total number of upstream Slots per Frame - variable
- BR number of Request of Bandwidth Slots per Frame
- AW Admit Window time duration

3.5. Modulation

Characteristics:

Type: QAM (Quadrature Amplitude Modulation)
Modulation States: 4/16 (with possible extension to higher modulation states e.g. 64)

Motivation of the choice.

QAM is a well known and field proven modulation technique which allows to achieve high spectral efficiencies. This is demonstrated by its use in practically all high capacity digital radios and also by medium/low capacity radios for point to point applications, every time a high spectral efficiency is required.
As QAM is a linear modulation format, an additional control of the transmitted spectrum is obtained with a proper spectrum (or pulse) shaping (e.g. raised cosine signals controlled by a roll off factor).
QAM also provide better performance in terms of Eb/No with respect to other kinds of modulations, like MPSK) which could, in principle, achieve the same spectral efficiency.

QAM modulation and demodulation (even in burst mode) functions can be, nowadays, easily generated with an full digital processing (adopting DSP techniques and VLSI integration and high frequency, high resolution A/D and D/A conversion). The processing can be extended at IF level. even at high symbol rates, thus allowing for an economic implementation.

Another important aspect to be considered is the impact of the microwave technology on the choice of the modulation format. As 802.16 radio systems will operate in the vicinity of 30 GHz, and in any case in the range from 10 to 66 GHz (see: Preliminary Draft Working Document for 802.16 Broadband Wireless Access System Requirements), we have to face mainly with the typical problems and limits of mm wave technology.

Basically we have to consider two points:
1. Transmitted power
2. Oscillator phase noise (and frequency instabilities)

In order to make an efficient use of the available power (which has a high cost) the choice would push toward the use of constant envelope modulation formats (like FSK, CPM and so on). However it can be easily shown that this choice would not meet the required spectral efficiency. QAM seems apparently to be penalised, however, as an example, a practical output back-off of 8 dB is enough to guarantee high quality operation for a 16 QAM associated with a raised cosine spectrum with a roll off factor of 0.2, especially if the system is equipped with some kind of error correction.

The second point is, in our opinion, a much more critical issue. In fact, phase noise and frequency instabilities (frequency jumps) are, at these high frequencies, a limit of the present technology. The consequence is that the modulation format must be chosen in order to be intrinsically robust against phase noise. QAM is reasonably insensitive, provided that the bandwidth of the carrier recovery loop is kept sufficiently wide with respect to the phase noise bandwidth. This is possible if the symbol frequency is sufficiently large, i.e. if the capacity per carrier is maintained reasonably high. In this proposal the minimum symbol frequency is about of 6 MHz, a value which guarantees a correct operation with typical values of phase noise presently achievable.

According to the system requirements, the primary cause of time variant impairments is rain fall. This is due to the high frequencies of operation (typically around 30 GHz). Secondary effect can be due to multipath fading, leading to frequency selective attenuation, when 802.16 systems are required to operate close to the lower limits of the specified frequency range (i.e. close to 10 GHz). It turns out that some amount of protection vs. frequency selective fading must be provided, at least optionally.
QAM modulation formats are easily equipped with adaptive equaliser (basically implemented with an adaptive FIR filter structure), as it is demonstrated by the extensive use of such equipment in digital radios. In a burst mode application the key point is to be able to estimate the channel distortion on a burst to burst mode. This can be done with a suitable preamble whose length depends on the number of taps of the FIR filter. As a general rule, two symbol per tap in the preamble are sufficient (example 16 symbols for a 8 tap equaliser).
Equalization requirements (DFM or Signature) need to be better defined before entering in a more detailed specification of the structure of the preamble.

4. System Capacity and scalability

Several System Capacity configurations will be possible based on the Channel Arrangement and on the adopted modulation and duplex scheme. Some examples are provided in the following.

- **FDD scheme**

Temptatively, a Frame time duration of FT=5.8 msec is assumed. If this is the case, one Time Slot per Frame will be suitable for the transport of an equivalent 64000 bit/s capacity.

The following combinations of Channel Arrangements/System Capacities are allowed:

Channel Arrangement (MHz)	*modulation QAM*	*rough Bit Rate (Mbit/s)*	*total number of Time Slots per Frame DN*	*Frame time duration (msec)*
12.5	4	21	210	5.8
	16	42	420	
	64	63	630	
25	4	42	420	
	16	84	840	
	64	126	1260	
7	4	12	120	
	16	24	240	
	64	36	360	
14	4	24	240	
	16	48	480	
	64	72	720	
28	4	48	480	
	16	96	960	
	64	144	1440	

Capacity is referred to one direction only.

The same number of Time Slots will be available in downstream and upstream. A small amount of the reported upstream capacity will be used for Admit and Request of Bandwidth operations.

As an example, an Admit window AW=96 microsec. will allow an automatic ranging up to 13 Km distance. This AW will correspond to two Time Slots in the System configuration with 7 MHz and 4QAM.

- **TDD scheme**

Temptatively, a Frame time duration of FT = 2 msec is assumed.

The following combinations of Channel Arrangements/System Capacities are allowed:

Channel Arrangement (MHz)	*modulation QAM*	*rough Bit Rate (Mbit/s)*	*total number of Time Slots per Frame DN+UN*	*Frame time duration FT (msec)*
12.5	4	21	75	2
	16	42	150	
	64	63	225	
25	4	42	150	
	16	84	300	
	64	126	450	
7	4	12	40	
	16	24	80	
	64	36	120	
14	4	24	80	
	16	48	160	
	64	72	240	
28	4	48	160	
	16	96	320	
	64	144	480	

Capacity is referred to both directions.

The number of Time Slots that will be available in downstream and upstream will depend on the actual boundary between the two phases. This limit will be set by configuration or changed dynamically based on the actual conditions of the traffic load.

For the Admit Window the same considerations apply as for FDD.

- **Adaptive Modulation**

The need to cope with the intrinsic variable nature of the radio channel propagation conditions and to take into consideration the possible different distances between the Subscriber Station and the Base Station, leads to the choice of a flexible and/or adaptive modulation scheme for future implementations.

The basic assumption is that the Time Slot duration is fixed, and chosen by configuration during System setup.
The adaptive modulation will allow putting more than one MAC PDU into the same Time Slot.
For example, if the basic System configuration allows for 1 packet per Slot with the 4 QAM modulation, 2 (3) packets will be put into the same Slot in case of 16 (64) QAM modulation. The packets will share the same Preamble and Guard time. Two (3) MAC PDU's will be inserted into the Slot, each one with its own FEC field.

The choice of the Modulation scheme will be done automatically per-Subscriber Station, among a pre-selected subset of modulation schemes, and will be based on the detected performance for that Subscriber Station. The required information for modulation selection will be exchanged with the support of the MAC. A detailed description of the related protocol will be submitted later.

- **Asymmetric Capacity**

The cost optimization of the radio parts of the Subscriber Station can lead to the adoption of an HPA with a power lower than the Base Station HPA.
The flexible modulation scheme allows this asymmetry as an intrinsic possibility. This will lead to an asymmetric Eb/N0 requirement, and consequently to an asymmetric transmitted power.
This will be suitable for those applications where the required upstream information rate is lower than the downstream one, because of the prevalence of browsing-type applications.

For those applications that allow TDD the asymmetry is intrinsic.

- **Multicarrier Configurations**

An additonal cost reduction in the Subscriber Station can be obtained by means of the partitioning of the available bandwidth into sub-channels where SubCarriers are allowed, each one with lower capacity. For example, 2 or 4 SubCarriers can share the overall channel; each SubCarrier will be used for a predefined sub-population of the Subscriber Stations; each Subscriber Station is assigned to a predefined SubCarrier, both downstream and upstream; the SubCarrier will be selected off line. This will lead to a reduction of the bit rate assigned to one Subscriber Station.

5. Power Budget and Performance

The required performance can be reached with the following assumptions:

- Receiver side Eb/N0 = 11.5 dB for 16QAM
  Eb/N0 = 7.5 dB for 4QAM

  allowing a 10^{-6} BER after correction.

- Transmitter side OBO = 4 dB, for 4QAM
  OBO = 8 dB, for 16QAM

The maximum allowed Reference System Gain will be:

$$RefSystemGain = TxPower - OBO - (Eb/N0 + Nf + 10 \times LOG_{10}\ BitRate\ (Mbit/s) - 114)$$

Some examples are provided, based on a TxPower = 0 dBW and Nf = 0:

Channel Arrangement	*modulation*	*Reference System Gain*
12.5 MHz	4QAM	119 dB
25 MHz		116 dB
7 MHz		122 dB
14 MHz		119 dB
28 MHz		116 dB
12.5 MHz	16QAM	108 dB
25 MHz		105 dB
7 MHz		111 dB
14 MHz		108 dB
28 MHz		105 dB

6. Embedded management of the Physical Layer

The Physical Layer will be able to support the automatic power control of the Subscriber Station based on the power level received by the Base Station.
Also dynamic time phase adjustment of the upstream burst inside the Time Slot will be done automatically.
The information necessary for adjustment will be sent to the Subscriber Station by means of PLOAM messages.
The scheduling of PLOAM messages will be provided by the MAC layer.
The detailed protocol will be submitted later.

7. Acronyms and abbreviations

BS	Base Station
DL	Downlink
DS	Downstream
DLC	Data Link Control
FEC	Forward Error Correction
LLC	Logical Link Control
MAC	Medium Access Control
PL	Physical Layer
PMP	Point-to-Multipoint
SS	Subscriber Station
PMD	Physical Medium Dependent
TC	Transmission Convergence
TDM	Time Division Multiplex
TDMA	Time Division Multiple Access
UL	Uplink
US	Upstream
PLOAM	Physical Layer Operator and Maintenance
UW	Unique Word

– downlink direction : from the Base Station towards the Remote Station
– uplink direction : from the Subscriber Station towards the Base Station

8. Acknowledgment

This contribution is fully based on the research and development activities undertaken by several project partners within the SIEMENS family. The authors present this contribution on behalf of these partners who are the major contributors to this proposal.