MAC Protocol Design for the Support of DBA in OFDMA-PON Networks

Wansu LIM[1], Ali GLIWAN[1], Pandelis KOURTESSIS[1], Konstantinos KANONAKIS[2], Ioannis TOMKOS[2], and John M. SENIOR[1]

[1]*University of Hertfordshire, Hatfield, Hertfordshire, AL10 9AB, UK*
Email: w.lim9@herts.ac.uk, a.gliwan@herts.ac.uk, p.kourtessis@hers.ac.uk, j.m.senior@herts.ac.uk
[2]*Athens Information Technology (AIT), 0.8 km Markopoulou Av, Athens, 19002, Greece*
Email: kkan@ait.edu.gr, itom@ait.edu.gr

Abstract: Original MAC frame formats have been developed to provide recommendations for new protocol designs in OFDMA-PONs. The portrayed scalability of the Dynamic Subcarrier Allocation (DScA) protocol is complemented by the granularity of hybrid OFDMA/TDMA topologies. Modelling of the DScA performance in OPNET has recorded the maximum 312.5 Mbits/s transmission rate capacity per ONU achieved at less than 2 ms packet delay and more than 95% network throughput depending on ONU offered load.

Keywords: MAC protocol, OFDMA-PON, Dynamic bandwidth allocation

1. Introduction

According to Next Generation PON1 (NG-PON1) specifications [1], the average data rate for residential users or small businesses is expected to grow symmetrically to more than 300 Mbit/s mainly due to emerging applications such as UHDTV, 3DTV, real time TV/VoD zapping and streaming, cloud 3D gaming, business E-Line P2P etc. Telecom operators also recognize that corporate/business users and Telco services require distinctive, higher performance access solutions. In addition, in support of wireless backhauling, Base Station bandwidths could reach up to 400 Mbits/s with current deployment scenarios and up to few Gbits/s with their future extensions [2]. To consolidate these diverse requirements, OFDM transmission over Passive Optical Networks (PONs) [3, 4] has been gaining in capacity, reach and cost-effectiveness. The FP7 STREP ACCORDANCE [5] enables seamless OFDM-based access and the coexistence of Ethernet, wireless, optical access, copper-based and novel OFDMA/dynamic subcarrier allocation network terminations. Developments in dynamic Medium Access Control (MAC) protocols for OFDMA networks are currently restricted to two key proposals, [6, 7]. PONIARD [6] portrays hybrid OFDMA/TDMA bandwidth allocation only at an inter-slice level (slices are the equivalent of the ACCORDANCE segments, i.e. large groups of subcarriers), with pure TDMA used otherwise. In [7], the fixed burst transmission (FBT) protocol treats each data transmission as a fixed burst aggregating several packets. Polling/request or report/grant signalling is employed for bandwidth reservation within one burst time. Alternatively in dynamic circuit transmission (DCT) transmission resembles a dynamic short-lived/long-lived circuit, only employing three-way signalling for service connection. As a result DCT could result in increased queuing delays, especially in the case of very short-lived connections, while not being able to handle rapidly fluctuating traffic. Allocation of subcarriers to ONUs in ACCORDANCE is achieved using OFDMA/TDMA at the finest granularity. The latter is particularly beneficial at limited subcarrier availability at network segments and/or when ONUs requires bandwidth much less than the 300-400 Mbits/s, potentially available in a single subcarrier. To further enhance network granularity, the frame control fields are designed to also support adaptive subcarrier modulation (adaptive capacity control).

2. ACCORDANCE Network Architecture

The ACCORDANCE network is designed to support diverse connectivity terminations. Apart from legacy PONs and xDSL, it portrays the convergence of OFDMA in a wireline fashion as well as in combination with wireless networking. To achieve the set objectives in a converged optical/wireless end-to-end network, the Central Office (CO) must be able to acquire instant bandwidth requirements from users terminated either to optical interfaces (converged optical/wireless) or wireless interfaces (pure wireless). In addition, an efficient bandwidth utilization mechanism must be provided adhering to SLAs and the appropriate CoS indicators. The latter depend on the converged technologies e.g., different types of CoS exist in GPONs, EPONs and LTE/WiMAX. Therfore, it is necessary to employ novel MAC protocols which will be tailored for the ODFMA-PON case and will allow for bandwidth allocation in the sub-carrier granularity, possibly even eliminating the need for TDMA approaches.

3. ACCORDANCE MAC Protocol

The ACCORDANCE frame control fields are defined to achieve OFDMA/TDMA operation accounting for legacy G/EPON protocols and their modification to host the essential functionalities. In GPONs, that implies additional fields are introduced in the header of downstream (DS)/upstream (US) frames, while in EPONs structural changes required at the GATE and REPORT MPCP messages. The ACCORDANCE DS header is shown in Figure 1 (a).

A unique throughout the network, ONU identifier, ONU_ID, field allows the total number of supported ONUs to reach 4096, whereas the ONU specific, Class of Service, CoS, field can accommodate up to 16 classes. These are sufficient to account for both the 5 T-CONT types currently defined in GPON, as well as the 8 Diffserv classes of EPONs. The ONU_ID and CoS fields provide ONUs with a unique identifier of a logical queue, much like the Alloc-IDs used in GPONs. New to the DS frame header is the SubCarrier Allocation identifier, SCA, field used by the OLT to specify the bandwidth assignment scheme for each ONU. The bits allocated to this filed distinguish between a Fixed Subcarrier Allocation (FScA), Dynamic Subcarrier Allocation (DScA), Dynamic Time and Subcarrier Allocation (DTScA), and Rectangular Dynamic Time and Subcarrier Allocation (RDTScA) mode of operation, exhibiting both pure OFDMA and OFDMA/TDMA allocation protocols. In FScA and DScA the Low_SC and High_SC fields are used to define the assigned subcarrier group range. The distinction lies on the fact that in FScA subcarrier groups are allocated to ONUs continuously while in DScA subcarrier groups are allocated to ONUs only for the next upstream transmission window, achieving dynamic scheduling and leveraging statistical multiplexing. In addition to the Low_SC and High_SC fields, the hybrid modes achieve additional dynamicity by allowing ONUs to share the specified subcarriers groups. To that effect, the LSC_Start_Time field determines the instant the lowest subcarrier in the predefined group is allocated to an ONU, while the HSC_Start_Time determines the end of that ONU’s transmission in the highest subcarrier. To further enhance OFDMA/TDMA flexibility, the OLT in RDTScA assigns to each ONU

2-dimensional rectangles. Each rectangle is uniquely defined by the points (Low_SC, LSC_Start_Time) and (High_SC , HSC_Start_Time).

(a)

ONU_ID	CoS	Mod	Rep_Type	SCA	Low_SC	High_SC	LSC_Start_Time	HSC_Stop_Time
12 bit	4 bits	4 bits	1 bits	4 bits	8 bits	8 bits	16 bits	16 bits

(b)

ONU_ID	CoS_T	Sup_Mod	SP_ID	ONU_Type	ONU_LSc_ID	ONU_HSc_ID
12 bit	4 bits	4 bits	4 bits	4 bits	8 bits	8 bits

(c)

ONU_ID	CoS	Length
12 bit	4 bits	24 bit

Figure 1 (a) DS protocol fields, (b) ONU registration fields and (c) ONU reporting fields.

The ACCORDANCE US frame incorporates fields addressing ONU Registration and buffer reporting as shown in Figure 1 (b) and Figure 1 (c). With regards to ONU registration fields such as the ONU_ID and CoS are still required. The ONU_LSc_ID and ONU_HSc_ID fields define the start and end of the subcarrier range assigned to an ONU and a service provider identifier, SP_ID, field allows for multiple service provider support. In reference to this field various ONU terminations can be identified by means of an ONU_Type field, distinguishing for example between an OFDMA/DSC ONU and an ONU/BS. To perform ONU registration the OLT updates individual ONU information by means of an OLT lookup table, used to store the static parameters necessary during the bandwidth allocation.

A unique feature of the ACCORDANCE protocol is its potential to control ONU bandwidth by adjusting the US subcarrier modulation. For this reason, a Sup_Mod field is used in the DS frame header to indicate the QAM efficiency employed in an ONU. This requires the OLT to constantly monitor the transmission performance (e.g. BER) by exchanging MAC Physical Layer Administration and Maintenance (PLOAM) messages to determine which options are eligible per ONU. In addition, the registration messages should be enhanced with information regarding the maximum QAM levels supported by each ONU. Apart from the already indicated fields, the OLT holds information about each ONU's SLA, the segment it is connected to and operating wavelength.

4. Bandwidth Scheduling Algorithm

The protocol allows for the bandwidth allocation process per segment to be performed in a reporting or non-reporting manner, specified by the Rep_Type field in the DS header. Since communicating grant/report packets between the network ONUs and OLT increases the ONU queuing delay, the protocol utilizes a non-reporting, constant traffic monitoring to evaluate each SC's usage by dividing the transmission time into monitoring windows. The flowchart of the DScA algorithm described above is displayed in **Error! Reference source not found.**, and consists of the following steps:

<u>*STEP 1*</u>: By the end of each window, the OLT calculates the average subcarriers used per ONU during the preceded monitoring window time.

<u>*STEP 2*</u>: As a result ONUs are partitioned into two groups; the *overperforming* and *underperforming* ONUs

- *overperforming* group: *Pre_SC* = *Used_SC* (It is impossible that *Used_SC* is greater than *Pre_SC*).
- *underperforming* group: *Pre_SC* < *Used_SC*.

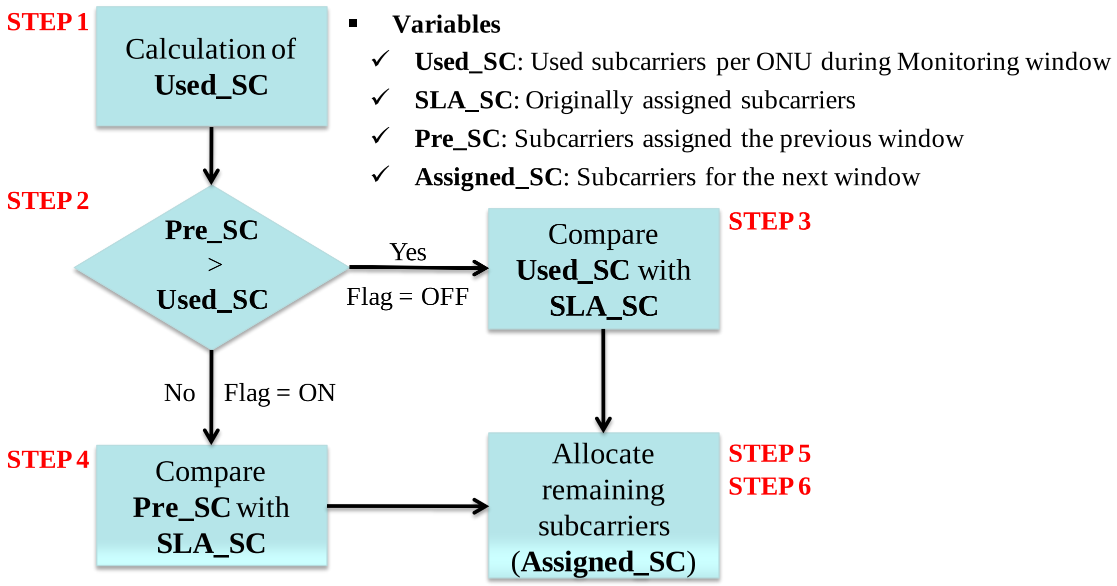

Figure 2 Flowchart of dynamic subcarrier allocation algorithm

STEP 3 (*underperforming* group from *STEP 2*): The OLT compares *Used_SC* with *SLA_SC* using different reference subcarriers to distinguish SLA grades. The following cases are considered:

- If *Used_SC* is smaller than or equal to *SLA_SC*, then the OLT defines *Assigned_SC* based on the *Used_SC*, subtracts *Used_SC* from *SLA_SC* and assigns the difference to the pot of "remaining subcarriers", signifying the subcarriers available for use elsewhere in the network.
- If *Used_SC* is greater than *SLA_SC*, then the OLT defines *Assigned_SC* equal to *SLA_SC* because it is not aware at this stage if there are "remaining subcarriers".

STEP 4 (*overperforming* group from STEP 2): The OLT compares *Pre_SC* with *SLA_SC* without considering the *Used_SC* since it has already determined in STEP2 that ONUs require more subcarriers. The additional subcarrier allocation is performed as follows:

- If *Pre_SC* is smaller than *SLA_SC*, then the OLT increments *Pre_SC* by 1 (*Pre_SC* + 1) and allocates it to *Assigned_SC*. Then it subtracts *Assigned_SC* from *SLA_SC* and assigns this difference to the "remaining subcarriers".

  If *Pre_SC* is greater than or equal to *SLA_SC*, then the OLT defines *Assigned_SC* equal to *SLA_SC* because it is unaware at this stage if "remaining subcarriers" are available or not.

STEP 5: After completing STEPs 2, 3 and 4, the OLT gathers the "remaining subcarriers" from the first case of STEP 3 and STEP 4 and distributes them to requesting ONUs based on their SLA priority.

STEP 6: Following STEP 5 and if there are "remaining subcarriers" the OLT assigns them to ONUs on SLA priority.

5. Simulation Results

To investigate the merits of the ACCORDANCE MAC protocol, an OFDMA-PON network operating under the DScA mode was developed using OPNET Modeler comprising 32

ONUs located at 40 Km. The buffer size in each ONU is limited to 10 MBytes. Total upstream data capacity is 10 Gbits/s, arranged in 64 subcarriers of 156.25 Mbits/s each. The packet size is uniformly generated between 64-1518 Bytes using Self-similar traffic with a 0.8 Hurst parameter.

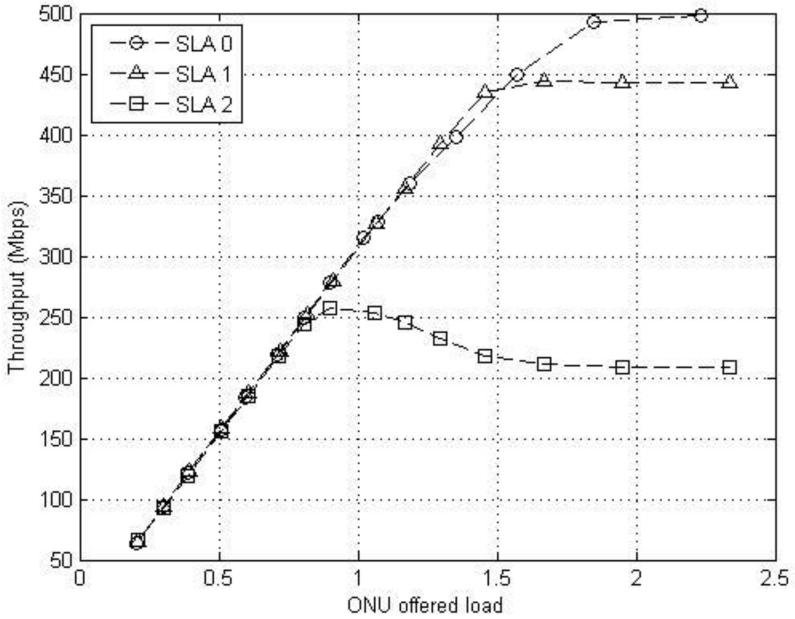

Figure 3 Throughput according to three SLA levels

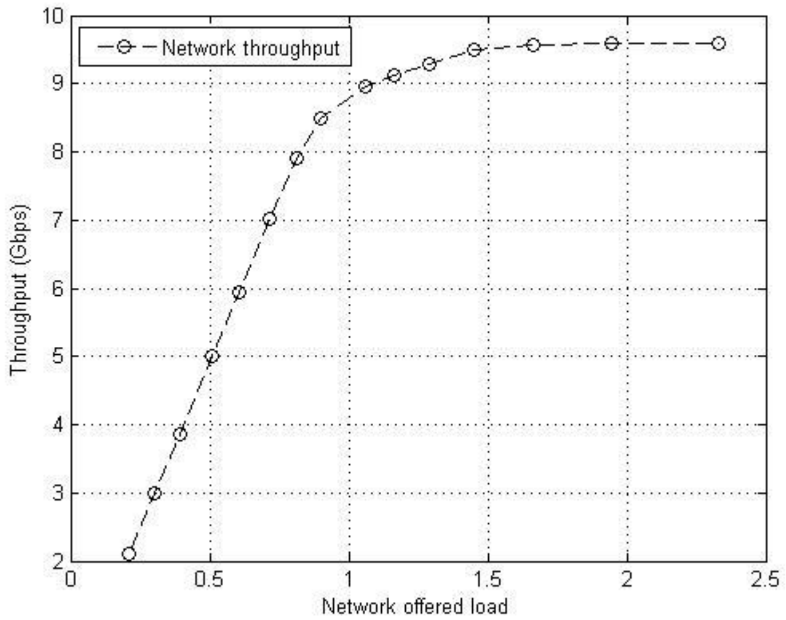

Figure 4 Network throughput

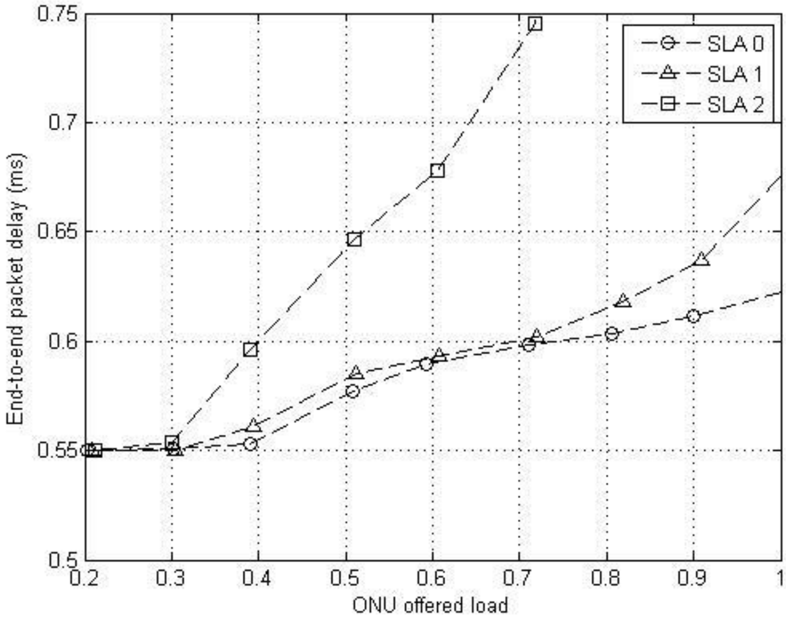

Figure 5 End-to-end packet delay for DScA

Figure 3 presents the throughput against ONU offered load according to three SLA levels as a function of ONU offered load. A load of 1.0 corresponds to a data rate of 312.5 Mbps (10 Gbps divided by 32 ONUs). The saturated throughput is 500 Mbps, 450 Mbps and 200 Mbps corresponding to high to low SLAs respectively. Figure 4 illustrates the network throughput versus the network offered load. A load of 1.0 corresponds to a data rate of 10 Gbps (total upstream data capacity). The DScA algorithm utilizes 96 % of total capacity. Figure 5 confirms the end-to-end packet delay of high and middle priority SLAs is less than 0.7 ms even if the ONU offered load is 1.0. This is because the guaranteed bandwidths of the high and middle SLAs are greater than or equal to the ONU offered load of 1.0 corresponding to 312.5 Mbps. In addition, the DScA algorithm allocates the remaining subcarriers according to the SLA priority. As expected, the end-to-end pack delay of low priority SLAs dramatically increases at an ONU offered load of 0.7 since a DScA algorithm cannot support granularity and subcarrier sharing among low bandwidth ONUs.

6. Conclusions

With the scope of providing recommendations for original MAC protocol designs for OFDMA-PONs, a summary of the ACCORDANCE network features closely associated and highly expected influencing the definition of the potential network MAC have been presented. Since packet multiplexing in the Ethernet or IP layers could be sufficient to broadcast data (OFDM/TDM) in DS, only the US protocol functionalities have been demonstrated. To that extend new frame control fields have been presented, allowing for the operation of four distinctive protocol modes. Ranging from fixed and dynamic pure OFDMA to dynamic and rectangular hybrid OFDMA/TDMA the devised protocols could mutually exhibit transparent pipes for distinctive ONUs (e.g. wireless BSs), statistical multiplexing, increased granularity and 2-dimensional allocation. The performance capabilities of the DScA protocol have been presented.

7. Acknowledgement

The work in this paper was partly carried out with the support of the EU FP7 STREP project ACCORDANCE.

References

[1] F. Effenberger, H. Mukai, P. Soojin, and T. Pfeiffer, "Next-generation PON-part II: candidate systems for next-generation PON," in *IEEE Comm. Mag.*, **47**, 50-57, (2009)
[2] A. Ghosh et al., “LTE-advanced: next-generation wireless broadband technology,” IEEE Wireless Communications **17**, 10-22 (2010).
[3] C. W. Chow et al., “Rayleigh Backscattering Performance of OFDM-QAM in Carrier Distributed Passive Optical Networks,” PTL **20**, 1848-1850 (2008).
[4] N. Cvijetic, D. Q. Junqiang and H. T. Wang, “Orthogonal frequency division multiple access PON (OFDMA-PON) for colorless upstream transmission beyond 10 Gb/s,” JOSA A **28,** 781-790 (2010).
[5] K. Kanonakis et al., ``ACCORDANCE: A novel OFDMA-PON paradigm for ultra-high capacity converged wireline-wireless access networks," In Proc. ICTON (2010)
[6] W. Wei, et al., “PONIARD: A Programmable Optical Networking Infrastructure for Advanced Research & Development of Future Internet, ” JLT **27**, 233-241 (2009).
[7] W. Wei, T. Wang, D. Qian and J. Hu, “MAC Protocols for Optical Orthogonal Frequency Division Multiple Access (OFDMA)-based Passive Optical Networks, ” in Optical Fiber communication/National Fiber Optic Engineers Conference (OFC/NFOEC), San Diego, 2008, pp. 1-3.