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Integrated Control Platform with Load Balancing Algorithm in Hybrid Optical Wireless Networks

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Abstract—In this paper we cover the problem of load balancing in terms of optimum cell selection and wireless channel condition in the hybrid optical wireless network. For a given set of multimedia users with minimum quality of service requirements and a set of best effort users we find the optimum resource allocation that guarantees services for the users and maximizes the total network utility. Our model applies for the convergence network of EPON and WiMAX where the TDM-like resource assignment scheme and the WiMAX air interfaces are used. We achieve convexity of the problem and solve the optimization problem. The proposed algorithm is simulated using MATLAB and the results show validation of the framework, i.e., load balancing scheme gains better network performances.

Keywords- EPON, WiMAX, load balancing, cell breathing, wireless channel condition, hybrid optical wireless networks

I. INTRODUCTION

The main appeal of Hybrid Optical Wireless (HOW) network is that it provides both high bandwidth and user mobility. An integration of EPON and WiMAX network is an example of the HOW network, which is a convergence of an EPON deployed as a backhaul and multiple WiMAX networks connected as the front-end networks. However, since the optical- and wireless- technologies are originally designed for different access areas, it poses significant challenges to multiple network cooperation such as routing, resource management, and quality-of-service (QoS) provisioning, especially when multimedia services are applied. Although there are existing control schemes in both EPON and WiMAX networks, simply connecting two networks may cause limitations of network performances because of differences in their physical infrastructures.

In the hybrid network architecture, the resource management plays a key role to ensure an efficient usage of both optical link and radio spectrum. This is of particular importance for next generation broadband access networks which support data, voice and multimedia services (tri-play services) to multiple users simultaneously. To improve network performance, many hybrid network architectures and management schemes have been proposed [1]-[5] to allocate network resources efficiently and integrally, for the purpose of provisioning end-to-end QoS among both optical and wireless network layers. A system level scheme, an integrated control infrastructure, is required to be considered

since most of research efforts in this field have been focused on either EPON or WiMAX solely. Our previous studies [4] shows that the hybrid network demands an integrated control plane to achieve overall and cooperated administration. Several system functions are addressed, including routing, scheduling and call admission control.

In this paper, we follow up the investigation of the integrated control platform in the hybrid EPON and WiMAX network. In particular, we explore a load balancing scheme using the cell breathing technique. The concept of cell breathing is used in conventional cellular networks to dynamically change the coverage area of cell towers [7]-[11]. Fully loaded cells contract their coverage area whereas the lightly loaded cells expand their coverage area. Basic idea of load balancing is to relocate users in overlapping region from fully loaded cells to lightly loaded cells. Our goal is to propose a novel integrated load balancing scheme, which utilizes a cooperative signaling protocol to collect WiMAX network status and makes centralized power assignment decisions in the EPON.

The hybrid EPON and WiMAX network architecture is illustrated in Figure 1. which delivers services to both

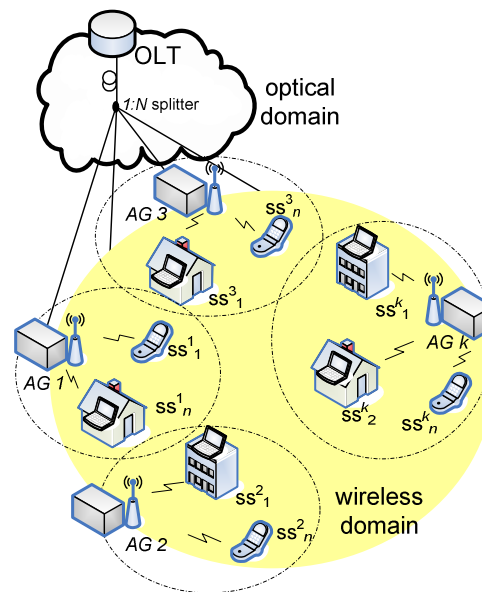


Figure 1. Hybrid EPON and WiMAX network architecture

wireline and wireless users. In EPON, a centralized Optical Line Terminal (OLT) communicates with multiple connected Optical Network Users (ONUs) via a passive optical splitter. In the Point-to-Multipoint (PMP) WiMAX network, a Base Station (BS) manages channel allocation to Subscriber Stations (SSs) as a central controller. In hybrid network architecture, the ONU functions and BS functions are integrated into a single device, namely an *Access Gateway (AG)*, which handles connections within the wireless network, and connections cross both EPON and WiMAX network (shown in Figure 2.).

Traditionally network control mechanisms are designed separately and exclusively in either optical networks or wireless networks. The characteristics and challenges of the hybrid network architecture are ignored. The principles of hybrid EPON WiMAX network allow the OLT to distribute data to AGs, which further relay data to the target SSs. To take advantage of the centralized system and the integrated control scheme, we propose a load balancing algorithm together with the optical downlink scheduler, which is able to control the AG transmit power dynamically and relocate traffic load in the overlapping area away from the heavily loaded cell. We introduce a new approach for the hybrid EPON and WiMAX network, where integrated control platform are deployed to manage network resources to maximize the overall system performances. A centralized power allocation control is implemented in the OLT unit. Each front-end WiMAX base station is assigned with a proper power level, in advance with a predefined power adjusting scheme, then the Signal to Interference plus Noise Ratio (SINR) dependent resource assignment is applied to achieve quality transmission. This is done by exploiting a set of suitable power profiles that derive the maximum network throughput and user quality of service.

The remainder of this paper is organized as follows. Section II introduces the system model and formulates the power allocation problem. Section III presents our proposed cell breathing scheme for load balancing. Section IV shows our simulation results and analysis. Finally, conclusion is given in Section IV.

II. SYSTEM MODEL AND PROBLEM FORMULATION

We consider the hybrid architecture with multi-cell WiMAX frond-end network, where K AGs that are connects to a central control station, OLT, via the optical link as shown in Figure 1. The wireless network consists of a set of $k = \{1, \dots, K\}$ of cells and a set of $n = \{1, \dots, N\}$ users in each cell. The service area is partitioned so that each Subscriber Station (SS) is connecting to only one AG at any given time. For simplicity of presentation, a system

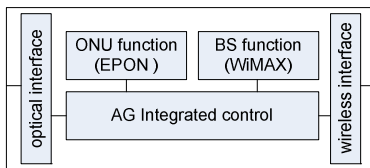


Figure 2. Integrated ONU and BS functions in AG unit

consisting of two cells is used to illustrate the cell breathing technique as shown in Figure 3. The operation area is modeled by a circle with a coverage radius (R_r^k). At any given time t , the cell sizes, the number of connected SSs, and the offered data rates to SS are varied by allocating a different transmitting power (P_t^k) to the AG^k . For instance, AG^1 initially is assigned with power P_t^1 and covers SS^1_{1-4} . After AG^1 is reported as overloaded, R_r^1 is contracted and its neighboring cell (R_r^2) is expanded in order to accommodate additional $SS^1_{3,4}$. Thus, the traffic load is balanced between AG^1 and AG^2 with minimized packet loss.

Within a WiMAX cell all users share the common channel by using a TDMA radio interface. Mobility is not considered in our simulation scenario, only stationary (e.g. fixed terminals) or quasi stationary users (e.g. pedestrian) are assumed. The delivery of the packets to subscriber users is performed on a TDM frame consisting of M slots. The size of cell coverage depends on transmit power, noise and path loss. The received signal at n th user in the k th AG, SS_n^k , is the attenuated version of the transmitted power level. The propagation model includes path loss, shadowing and fading. In this paper, an Erceg propagation model defined in the IEEE 802.16 standard is used [6].

$$P_n (dB) = 20\log_{10}(4\pi d_0/\lambda) + 10\gamma\log_{10}(d_0/d) + \Delta PL_f + \Delta PL_h + s \quad (1)$$

Where λ is the wavelength. γ is the path-loss exponent. d is the distance between the BS and receiver. d_0 is 100 m. ΔPL_f is the frequency correction term and ΔPL_h is the receiver antenna height correction term. s is a log-normal shadow fading component.

The mean received power (P_r) is the difference between the sum of the transmit power (P_t) and the antenna gains (G_a) and the path loss (P_n). The Signal to Interference plus Noise Ratio (SINR) is the ratio of received signal power to the interference signal power (I_n), which is computed using (2). There is a minimum acceptable SINR ($SINR^{thr}$) for receiving a quality satisfied signal.

$$SINR (dB) = P_r - I_n = P_t + G_a - P_n - I_n \quad (2)$$

Where I_n denotes the total interference received at each user, which consists of two parts: intra-cell interference and inter-cell interference. The intra-cell interference is caused from

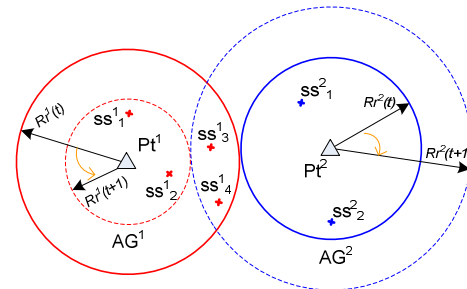


Figure 3. Cell breathing in wireless network. The solid circles represent initial coverage area (at time t) and the dotted circle represent adjusted coverage area (at time $t+1$).

other SSs within the cell and the inter-cell interference is caused from the neighboring BSs. In this scenario, TDMA scheme is applied and only one SS transmits during the assigned slot time. It is assumed that there is no mutual interference among SSs in a cell. On the other hand, the initial cell coverage of AG^1 and AG^2 are non-overlapping by assigning proper transmission power values in order to avoid cross-cell interference. The theoretical system throughput of a Single Input Single Output (SISO) system, AG^k , can be derived from the well-known Shannon capacity using the expression below (3):

$$T_{total}^k = \sum_{i=1}^N \log_2(1 + \text{SINR}^i), k \in K \quad (3)$$

Clearly, the throughput is determined by the interference level, the channel condition, applied transmitting power and the distance between AG and SS. For simplicity, we assume that the dynamic power control at AG to allow unique data rate for individual SS is not utilized here. Thus, once the transmission power for the k th AG during a slot time t , $P_t^k(t)$, is assigned, the system capacity can be estimated.

So we formulate the cell breathing problem as one optimization of the coverage of AG and the number of served SSs. Each AG^k attains its individual fixed transmitting power level during a time slot, P_t^k , to provide services with satisfied QoS constraints of each user, while optimizing the global multi-cell system throughput through balancing traffic load between AGs. Define $p = [p_1, \dots, p_{max}]$ as the vector of cell power levels assigned to AGs by the OLT. Then the system problem is

$$\text{maximize} \quad \sum_{i=1}^K T_i(p_i) \quad (4)$$

$$\text{Subject to} \quad p_l \leq p_i \leq p_{max} \quad \forall i \in K,$$

$$\text{SINR}_{ij} \geq \text{SINR}_{ij}^{thr} \quad \forall i \in K, \forall j \in N.$$

In the above program, the first constraint indicates that each AG is assigned within a maximum power p_{max} . The second constraint shows that quality transmission is ensured with assigned power. Our objective is to maximize the total throughput of the resulting power allocation.

III. CELL BREATHING SCHEME FOR LOAD BALANCING

EPON is a time division multiplexed (TDM) network and it relies on multi-point control protocol (MPCP) that bases on GATE and REPORT messages to grant and request for uplink bandwidth. The GATE message is broadcasted to all ONUs and target ONU receives the packets based on the labeled link layer identification (LLID). The REPORT message is reported to the OLT by ONU within its uplink transmission window. OLT allocates uplink bandwidth bases on either fixed bandwidth allocation or dynamic bandwidth allocation (DBA) algorithm. Here in the hybrid architecture, ONU functions are implemented into the AG unit.

In order to optimize the system and ensure overall QoS, we use the queue size and delay merit to determine whether or not a cell is overloaded. A cell overloading is said to occur, if the total queued data for all traffic classes at that instant exceeds a threshold, Q_{thr} , or delay to transmit the queued real-time traffic is violated to the requirement, D_{thr} . In the former case, the cell cannot take more traffic due to the buffer size limitation. In the latter case, the cell cannot guarantee real-time traffic with satisfied QoS requirements.

As shown in Figure 4, the cell breathing mechanism extends the MPCP control and incorporates two frames to achieve power control and load feedback. The two frames are GATE-p and REPORT-p. Similar to GATE, $GATE-p$ is broadcast downlink and contains a quantity pair (LLID and P_t) to indicate allocated power level to individual AGs. $REPORT-p$ is a modification of the existing REPORT message and adds the residual queue length (Q_{res}) and

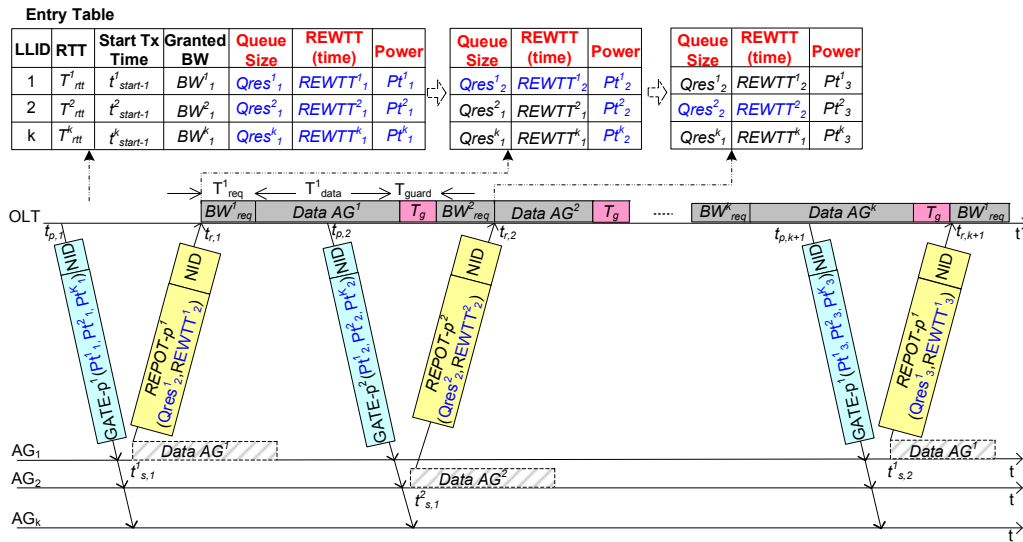


Figure 4. Extending MPCP with cell breathing algorithm

TABLE I. FROND-END WIRELESS SYSTEM PARAMETERS

Parameters	Value
SS distribution	Random uniform
Frequency band	3.5 GHz
System bandwidth	10 MHz
Propagation model	Erceg model; Propagation environment type C: flat terrain with light tree densities.
BS power	+40 dBm
fading st. dev.	8 dB
BS antenna gain	+ 17 dBi
SS antenna gain	0 dBi
BS antenna height	35 m above ground
SS antenna height	2 m above ground
Noise power	-138.41 dBm
Noise figure	7 dB

Residual Expected Wireless Transmission Time (*REWTT*) to the message. When DBA is employed versus fixed bandwidth allocation, REPORT-p message and the embedded downlink load information is feedback to the OLT aperiodically. In addition to avoid extended downlink traffic backlog, cell breathing can also be adjusted to relieve backlog due to poor channel conditions suffered at the AGs. To account for random wireless channel fluctuations, the feedback mechanism is important and necessary.

After receiving bandwidth requests from registered AGs, the granted bandwidth and transmission start time are assigned by the OLT without conflict. AGs are polled in sequence based on the scheduling police used in the OLT. In this example, AGs are polled in an order of their LLID number. The following cell breathing procedure is carried out in the OLT and AGs:

- At time $t_{p,1}$, the OLT broadcasts power assignments to its connected AGs via GATE-p message. Each AG adjusts its transmitting power and associates SSs.
- After receiving the GATE-p message, AG¹ is polled and starts its uplink transmission at $t'_{s,1}$. Along with data, the Q_{res} and *REWTT* information are reported to the OLT. At $t_{r,1}$, the initial entry table is updated.
- If the AG1 is sufficiently crowded, the OLT reduces the assigned power to AG¹ ($Pt_2^1 < Pt_1^1$) and increases its neighboring cell powers ($Pt_2^k > Pt_1^k$). The GATE-p message is broadcasted and all AGs adjust their transmission power levels.
- Since the subscriber device chooses the base station with the strongest Received Signal Strength Indication (RSSI) among all received signals from AGs. When the cell coverage changes, some subscribers in the overlapping region (e.g. SS¹₃, SS¹₄ in Figure 3. will be forced to handover to a less loaded neighboring cell.
- Although all AGs received the GATE-p message, only AG2 is polled at $t'_{s,2}$.
- The transmission power cannot decrease indefinitely. There is a minimum value and the power level is decreased step-wisely.
- The feedback from AG1 after decreasing its transmit power and contracting its region will be reported to the OLT at its next polling time, $t'_{s,2}$.

IV. SIMULATION RESULTS

We simulate the cell breathing scheme in MATLAB software. The EPON system is modeled as a tree topology, where an OLT connects to K cells ($K=16$ or 32) via optical link. The downlink optical transmission rate is 1.25 Gbps and data are broadcasted from the OLT to AGs. In the WiMAX system, network parameters are tabulated in TABLE I. For simplicity there is one AG per wireless cell. SSs are randomly allocated within the cell region.

For the simulation study, we consider one heavily loaded cell at AG¹. Few traffic arriving are designating to the neighboring cells of AG¹ and thus its neighbor cells are available to load balance bandwidth from the overlapped AG¹. The traffic is generated using Poisson distribution and the SSs are equally and uniformly distributed within each cell. The simulation compares the performances of the load balancing (LB) solution against without using load balancing (NLB). In the simulation, AG drops incoming packet when either the queue is full or if the delay requirement for real-time traffic is not met.

We first simulate the network throughput rate vs. input traffic amount (shown in Figure 5.). Input traffic amount is used instead of the input optical rate because optical line rate is significantly higher than wireless data rate. Thus, total input traffic amount is presented and the simulation generates the indicated amount of input traffic periodically over many periods. The LB solution increases the network throughput in excess of 40% at best and the improvements become more obvious when the input traffic load increases. It demonstrates that the proposed cell breathing operation can effectively handle heavy load in AG¹ by reduces the transmit power of AG¹ and reallocates boundary SS. In the case of NLB, AG¹ continues to serve the boundary SS, which overloads the AG while demanding relatively longer transmission time due to low SINR available at the crowded cell boundary. Hence it is advantageous to balance traffic load among cells.

Next shown in Figure 6. , the dropping probability is evaluated in different scenarios with different input traffic load. Under light traffic load, the dropping probability of LB solution is zero, which performs better than the NLB solution. However, when the input traffic load continues to increase, neither LB nor NLB can meet the delay requirement, i.e. 75 ms, for the real-time traffic. The gap between the two curves consists of the output throughput rate difference and the traffic load from the boundary area. We note that LB algorithm outperforms NLB and the amount of improvement depends on the availability of boundary SSs that can be reallocated to neighbor cells.

We also compare the scenario that 32 AGs are connected in EPON system with previous 16 AGs. When there are more AGs added, the interval between polling the same AG is increased. In other words, the period of receiving the feedback of power adjustment is increased, which may cause problem if the period is too long. However, as seen in Figure 7. LB scheme is well performed in the 32 AGs case, because

the time slot assigned to each AG is reasonable. Thus cell

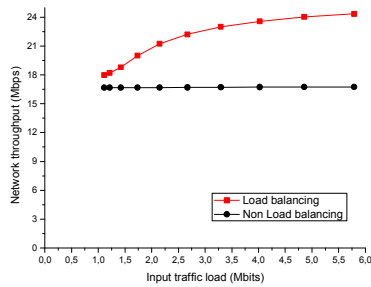


Figure 5. Network throughput enhances with cell breathing.

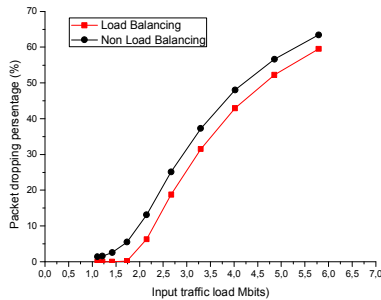


Figure 6. Packet drop probability reduces with cell breathing.

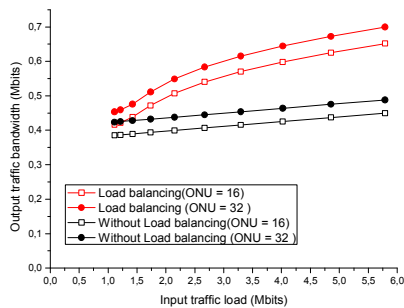


Figure 7. AG wireless output bandwidth comparison.

breathing scheme can be used with a larger number of AGs.

V. CONCLUSIONS

In this paper, a load balancing algorithm using dynamic power control to effectively adjust the size of cell coverage to maximize overall network capacity is proposed. In the OLT, the objective is to jointly make downlink scheduling decision and determine the transmit power.

The basic idea of this algorithm is when a cell sends out a heavily loaded indicator, the OLT starts redirecting some SAs that located in overlapping region to less loaded

neighboring cells by reducing the transmit power. The term 'cell breathing' is referred to the phenomenon where the size of a cell shrinks when the load increases, and expands when the load decreases. In this way, the heavily loaded cell can shift its load in the overlap area to its neighboring cells.

This algorithm, which we refer to as the integrated load balancing problem, improves two main network performances while ensuring that users achieve QoS targets. First, it eliminates the case that a cell becomes overloaded, which reduces the probability of packet dropping and overdue delay. Second, it increases the bandwidth utilization in multi-cell system.

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