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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 difference 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...
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 adjustment 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, ..., \( K \)\} of cells and a set of \( n \) = \{1, ..., \( N \)\} 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 simple presentation, a system 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 \( (R_i^c) \). 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 \( (P_{i_t}) \) to the AG. For instance, \( AG^1 \) initially is assigned with power \( P_{i_t} \) and covers SSs1,2,4. After \( AG^1 \) is reported as overloaded, \( R_{i_t} \) is contracted and its neighboring cell \( (R_i^c) \) is expanded in order to accommodate additional SSs3,4. 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, \( SS_n \), 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].

\[
P_n (dB) = 20 \log_{10} \left( 4 \pi d_0/\lambda \right) + 10 \log_{10} (d_0/d) + \Delta P_{PL} + \Delta P_{PL} s \quad (1)
\]

Where \( \lambda \) is the wavelength. \( \gamma \) is the path-loss exponent. \( d \) is the distance between the BS and receiver, \( d_0 = 100 \) m. \( \Delta P_{PL} \) is the frequency correction term and \( \Delta P_{PL} \) 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 \( (P_{PL}) \). 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 \( (SINR_{th}) \) 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 2. Integrated ONU and BS functions in AG unit](image1)

![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 \( t+1 \)).](image2)
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 $AG^i$ and $AG^j$ 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, $AG^i$, can be derived from the well-known Shannon capacity using the expression below (3):

$$T^k_{\text{total}} = \sum_{i=1}^{N} \log_2 (1 + \text{SINR}^{-1}), k \in K$$  

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 transmission power 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$^i$ attains its individual fixed transmitting power lever 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 $p = [P_1, ..., P_{max}]$ as the vector of cell power levels assigned to AGs by the OLT. Then the system problem is

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

Subject to $p_t \leq P_i \leq P_{max} \ \forall i \in K$,

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

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

Figure 4. Extending MPCP with cell breathing algorithm
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the time slot assigned to each AG is reasonable. Thus cell 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 SSs 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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