Efficient IP Mobility Management for Green Optical and Wireless Converged Access Networks

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Abstract— **During off-peak hours of a day, when incoming and outgoing traffic arrival rate used to be low, a Mobile Terminal (MT) can stay in idle mode for long time. For tracking the idle MTs, a wireless access network invokes them to conduct location update whenever they enter into a new location. This allows the network to route a call successfully. To provide any IP packet based service, Mobile IP (MIP) is very important protocol undeniably. However, Proxy Mobile IP was developed by IETF without considering idle mode condition of MTs. Consequently, an idle MT needs to conduct MIP binding (Layer 3 location update) whenever it moves to a new area of a Mobile Access Gateway (MAG) although it does not have any incoming or outgoing packets during idle periods. This phenomenon unnecessarily increases location update signaling cost. In our previous work, we proposed a mechanism using which only Layer 2 location update is needed when an MT is in idle mode and the Layer 3 location update is conducted after a call arrives for an idle MT in Optical and Wireless Converged Access Networks (OWCAN). This allows saving energy in the mobility management nodes (e.g. MAG, Base Stations) significantly.**

Based on our previous work, in this paper we propose a novel algorithm for the Optical Network Units (ONUs) of an OWCAN. This algorithm decides when to interrupt modules of a sleeping ONU to wake up and which frames should be forwarded for uplink transmission. We have found that adopting this algorithm an ONU of an OWCAN can save energy significantly. Therefore, our solutions mainly contribute in two-fold to make a green OWCAN. First, it minimizes energy consumption in the mobility management nodes. Second, our solution also reduces energy consumption and improves bandwidth utilization in the optical backhaul.

Keywords-component; Mobile IP; Location Update; Energy saving; TDM-PONs; Sleep mode; converged networks.

I. Introduction

Energy consumed by network equipments is huge [1]. It is estimated that in all over the world ICT consumes approximately 8% electricity [2]. It has been also found that the utilization of access network equipments is less than 15% and it consumes around 70% of overall telecom network energy [2].

Among all other access technologies, Passive Optical Network (PON) consumes lowest amount energy. However, it can provide huge data rate and lower Capital Expenditure (CAPEX). These characteristics have motivated some countries to deploy PON widely (e.g. Korea, Japan, China) [3]. Although PON consumes lowest amount of energy among all other access technologies, there is still room to reduce energy consumption in PON. Therefore, research effort both in Physical layer (i.e. Layer 1) and Medium Access Control (MAC) layer (i.e. Layer 2) is needed. Here, we briefly explain why research effort in IP layer (i.e. Layer 3) is also needed for reducing energy consumption in Optical Network Units (ONUs) along with Layer 2 and Layer 1 in an Optical and Wireless Converged Access Networks (OWCAN).

When a Mobile Terminal (MT) is in idle mode it listens the paging signals periodically and updates its location [5]. All wireless access technologies (e.g. IEEE 802.16e) require location update for idle MTs so that on call arrival, they can be paged at the right location. Interestingly, even the current Proxy Mobile IP (PMIP) protocol, developed by IETF, does not consider idle mode condition of MTs [6]. Therefore an idle MT needs to perform Layer 3 location update (PMIP binding) whenever it moves from one Mobile Access Gateway (MAG) Area to a new MAG Area (MA); even it doesn't have any active session. As a matter of fact, this procedure costs much in terms of location update signaling. There are some research solutions that suggest that as long as an MT is in idle mode there would not be any Layer 3 location update. While some researchers propose to conduct Layer 3 location update after crossing a certain distance [6].

Layer 3 mobility has been considered by several researchers in an OWCAN [7, 8, 9]. Besides, Fiber to the Home (FTTH) equipment manufacturers are coming up with Layer 3 functionality (i.e. MAG functionality) on top of MAC layers of an ONU [10, 11]. One of the possible reasons is that an ONU (e.g. 10G ONU in Ethernet PON) may serve many home subscribers or Base Stations (BSs) connecting MTs with its own network. Figure 1 depicts how an OWCAN might look when Layer 3 functionality is considered on top of ONUs' MAC layer.

In fact, mobility management in Layer 3 in an ONU with the aim of making energy efficient PON is a challenging issue as it has been being considered that an ONU should move into sleep mode when there is no upstream or downstream traffic is available [2, 3, 4, 19, 20]. In off-peak hours of a day, there might have lower traffic arrival rate than that of the peak hours. However, even in off-peak hours Layer 3 mobility management requires signaling message to flow between an

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access network domain to a core network domain. Consequently, it will force an ONU to wake up just for sending those tiny amount signaling messages for managing MTs' Layer 3 mobility. One possible solution for avoiding this situation is to postpone Layer 3 location update as long as an ONU is in idle mode [12]. However, postponing the signaling message transmission until an ONU's sleep interval ends might cause inexpedient situation (e.g. on call arrival downstream frames for an idle MT might be forwarded to previous serving ONU [12]). Therefore, apart from the MAC layer and Physical layer, research effort is needed in Layer 3 for a green OWCAN.

In our previous work [12], we proposed a solution for reducing energy consumption in the mobility management related nodes of OWCAN (e.g. MAG, Local Mobility Anchor (LMA)). In this paper, based on the previous work we propose to add a novel filtering algorithm at the ONUs of an OWCAN. This algorithm allows an ONU to be more energy efficient. In this paper, we consider existence of Ethernet PON (EPON) and WiMaX in an OWCAN. Therefore, as a whole, our solutions aims to reduce location update signaling cost and maximize energy saving in the ONUs of an integrated network of WiMaX and EPON. As this paper is an extension of our previous work [12], to maintain the flow of the paper we first present how our solution can minimize energy consumption in the mobility management nodes of an OWCAN. Then, we present the novel algorithm for ONUs. The remainder of this paper is organized as follows. Section II discusses related work. In Section III, we present our solutions. Performance analyses are presented in Section IV. Finally, Section V draws the conclusion and states future research direction.

II. Related Work

In this part, we first briefly explain how PMIP location update works and then we provide brief description about Time-Division-Multiplexing PONs (TDM-PONs) including possible approaches used in these access network technologies to make energy efficient.

A. Proxy Mobile IP (PMIP) Location Update Mechanism:

In PMIP, there are two important functional units: LMA and MAG. Packets sent by other nodes to the destination MT are received at the LMA within and beyond the PMIP's domain [13]. LMA creates and maintains a binding table, which keeps the record of each MT and the corresponding MAG. On packets arrival for an MT, the LMA encapsulates the incoming packets with Proxy Care of Address (Proxy-CoA) of the serving MAG and then forwards them towards that destination MAG. LMA also de-capsulates the outgoing packets from MT by removing LMA address (LMAA) and forwarding the packet towards its destination. Any incoming and outgoing packet of an MT should pass through MAG [13]. MAG encapsulates the packets with the address of the LMA and also decapsulates the packet when it receives from the LMA. When a new MT (any active or idle MT) arrives its coverage area (i.e. MAG Area), a MAG should send Proxy Binding Update (PBU) message to the LMA. And in reply, the LMA sends Proxy Binding Acknowledgement (PBA) message to that MAG for that MT.

B. Improvement of Energy Efficinecy in TDM-PONs:

In a TDM-PON, in the downlink direction the Optical Line Terminal (OLT) transmits frames conveyed by a single wavelength, then it is split by a passive. Therefore, downlink transmission is broadcast and select mechanism, while for the uplink communication (i.e. an ONU to the OLT) an ONU gets a dedicated time slot. In this shared medium, the OLT sends each of the frames after marking with an unique Logical Link Identifier (LLID) so that ONUs can recognize their own frames. As an ONU does not know when the OLT will have a downlink frame, it needs to be always on for receiving the downlink frames from the OLT. On the other hand, for transmitting uplink frames (arrived from customer premises), an ONU needs to wait for the dedicated uplink transmission slot.

To make TDM-PONs (e.g. EPON, Gigabit-PON (GPON)) energy efficient, researchers from industries and academia have proposed sleep technique for the ONUs (e.g. [3, 4, 19, 20, 21]). The basic approach for saving energy is keeping the ONUs in sleep mode whenever possible. ITU-T G-series recommends four different energy saving techniques for an ONU. Among them the techniques for saving energy in the optical interface is Deep sleep mode (i.e. turning off the transmitter and the receiver of an ONU), Dozing Mechanism (i.e. only the transmitter of an ONU is turned off when there is no uplink traffic available) and the Cyclic sleep mode where a transmitter and a receiver of an ONU is periodically turned off and on [20, 21]. ITU-T G series also recommends combining multiple energy saving techniques to maximize energy saving in GPON. For example, Cycle sleep mode can be used with Deep sleep mode [21]. Similarly, it is possible to make cyclic receiver or/and transmitter sleep [3]. Using such techniques, it is attainable to improve energy efficiency of TDM-PONs.

III. Proposed Efficient Mobility management for Green OWCAN

In this part, first we explain how solution presented in our earlier work in [12] contributes minimizing signaling cost (i.e. energy consumption) in the mobility management nodes of an OWCAN. Then, based on that solution (including the working principle and system model), we propose an algorithm for the ONUs of OWCAN in this part. In [12], our objective is to develop a scheme that can eliminate Layer 3 location update during the inter-call arrival time (MT's idle period) and can forward the packets from the LMA through the optical backhaul to an idle MT on call arrival without any service disruption. It is assumed that when the time between two calls arrival crosses a threshold value, T_{th}, for an MT, OLT assumes that the MT is in idle mode. Then based on this assumption, we present here how this solution works.

A. Mobility Management Mechanism in OWCAN for idle MTs:

- An idle MT moves from one MAG Area to another MAG Area inside the OWCAN, without performing any Layer 3 location update. When a call comes for any MT at the OLT, OLT resolves status of the MT (idle/active) from T_{th}. If the MT is in idle mode, OLT sends those packets after marking with a Special LLID (SLLID). At this point, it is important to mention that this SLLID is known to all ONUs in the PON domain. In other words, every ONU knows that the OLT forwards any idle MT's frame marking with this SLLID. If the inter call arrival time for any MT is less than T_{th} , the OLT assumes that MT is active and it is in the same MAG Area from where the last Layer 3 location update was conducted. If the MT is in active mode, the OLT resolves the corresponding LLID of that ONU from the Proxy-CoA of the serving MAG and then forwards the packets after marking with that LLID.

- On the other hand, when an ONU receives a frame marked with the SLLID, it extracts the packets inside. Then, it invokes the collocated Paging Controller (PC), which is a Layer 2 mobility agent in WiMaX architecture [6] (see Figure 1), asking all the idle MTs' lists of its MAG Area. The PC provides the list in reply. If the ONU finds any packet which is destined for any one of these idle MTs, it requests PC to page that MT to wakeup. After successful paging, the idle MT switches from idle mode to active mode. Then, those destined packets are forwarded through the serving BS to that MT.
- When the idle MTs wake up and start receiving packets, ONU collects all the PBU messages for Layer 3 location update from the collocated MAG, and then transmits to the OLT during dedicated uplink transmission slot.
- On arrival of PBUs at the OLT, OLT sends those to collocated the LMA. And finally the LMA updates its binding table (Layer 3 location update is performed).

As mentioned earlier, ONUs should move to sleep mode whenever possible to save energy by switching off some of its power hungry components like Photo Detector, Laser Driver, and Amplifier [4, 21]. Then, if the OLT sends frame marking with SLLID, at that time all the ONUs need to be in active mode to receive that frame. To facilitate this, we assume that for the downstream transmission OLT also consider a cycle time, T_{cycle}, as proposed in [3]. And for each of the T_{cycle} we suggest to put one fixed slot and during that slot time all of the ONUs under which any new idle MT comes should wakeup and wait for downstream transmission frames marked with SLLID. It is needed to mention here that T_{cycle} is considerably very small amount of time which can be even less than 3 ms [3]. Therefore, delay requirement for arrived VoIP call (10 ms delay for voice traffic recommended in IEEE 8021Q) can be satisfied easily for any idle MT.

B. Novel Algorithm for ONUs of OWCANs:

Earlier, we mentioned how an ONU functions when it receives any downlink frame. In this part, we explain the role of an ONU when it receives any uplink frame. An ONU basically composed of a Digital and an Analog module [4]. In the digital circuitry module there are several components such as Buffer, Processor. While in the Analog module there exists Transceiver-module, Amplifier, D-MUX etc. Similar to the proposal made in [4, 19, 20], we consider that an ONU moves to sleep mode whenever there is no uplink or downlink traffic available. Similar to [4], we assume that the digital module part of an ONU is remained on all the time. Furthermore, we assume there is a Sleep Control Unit (SCU), which decides when an ONU moves from one mode to other mode (e.g. sleep to active) and what role it should perform (e.g. transmit or/and receive). If there is any frame arrives, digital part of the ONU accepts those frames through the User Network Interface (UNI) and stores them into the Buffer.

Previously, we have stated our intention regarding postponing Layer 3 location update at the LMA as long as an MT is in idle mode. Therefore, to comply with our proposal made earlier we propose the following filtering algorithm for ONUs in OWCAN; so that, they can save energy.

Algorithm 1: *Frame selection (Proposed Filtering Policy)*
Check available frames in the buffer periodically. ***step 1.*** *If there are any available frames, check whether any of the frames contains PBU message or not.* ***step 2.*** *If there is any frame contains PBU message, check whether that frame is corresponding to any idle MT or not.* ***step 3.*** *Make an interruption to the SCU and notify that there are frames for uplink transmission if there are any frames in the buffer excluding those frames that contain PBU of idle MTs.*

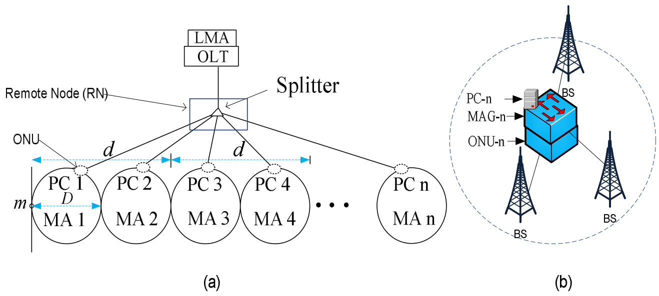

Figure 1: An OWCAN architecture: *a)* Overall architecture of an OWCAN; *b)* Wireless Network topology inside an MAG Area (MA).

When *Algorithm 1* is deployed in an ONU of an OWCAN, ONU will pass all frames excluding those frames which contain PBU of an idle MT. For better understating, we provide a semantic comparison between our solution, where an ONU uses filtering policy of *Algorithm 1,* and the conventional mechanism in Figure 2. We can notice that incase of convention scenario (See Figure 2 (a)), an ONU (e.g. *ONU-i*) forwards all the frames arrived frames the customer premises. In contrast, in our proposal (see Figure 2 (b)) an ONU forwards only PBUs of active MTs and all other data frames.

It must be noted that when an ONU moves from sleep mode to active mode it takes a particular amount of time, which is known as transition time (T_t), to complete synchronization with the PON network [20]. Then, especially during the off peak hours of day an ONU might need to wake up just for transmitting PBUs of idle MTs. In such scenario, an ONU in conventional mechanism will end up with spending energy for transiting for sleep mode to active mode and then transmitting those frames containing PBU message of idle MTs. For example, unlike at the time T_1 in Figure 2 (a) an ONU does not need to be active when our proposal is used (see Figure 2 (b)). At this point, it can be concluded that proposed *Algorithm 1* contributes in three-fold. First, it reduces uplink frame dropping probability. Second, it improves bandwidth utilization in optical backhaul. Finally, it saves energy in ONUs of an OWCAN. The validity of our solution is confirmed by simulation in following section.

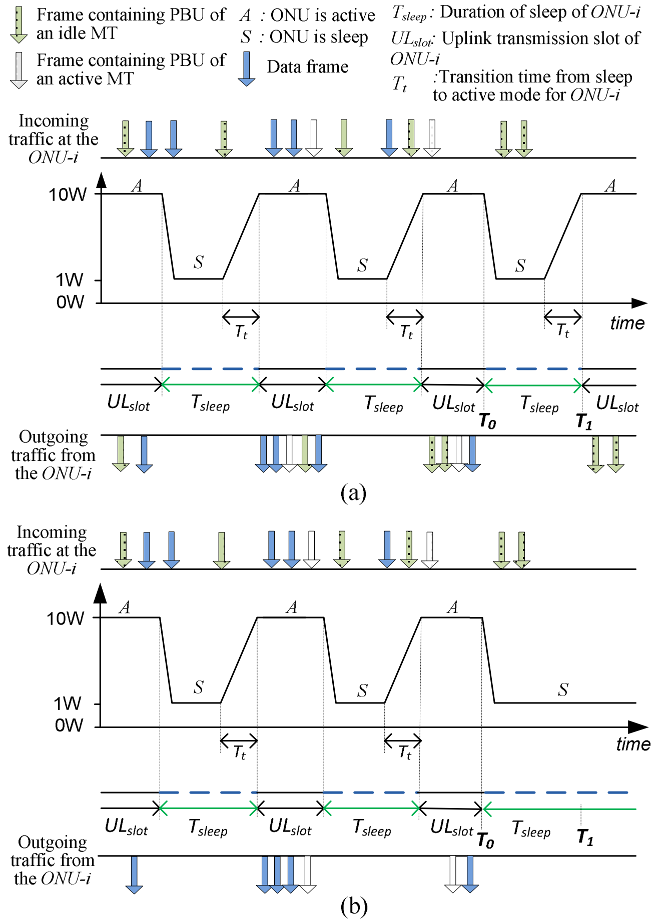

Figure 2: Schematic comparison of frame forwarding between conventional and proposed solution: *a)* Conventional mechanism; *b)* Proposed solution.

IV. Performance Analysis

In our previous work, we compare our solution in front of Distance Based Location Update (DBLU) scheme proposed in [6] and the Per MAG Location-Update (PML) scheme [15]. We try to measure energy consumption in terms of signaling cost during the time between two calls arrival for an MT. Detailed numerical analysis can be found in [12].

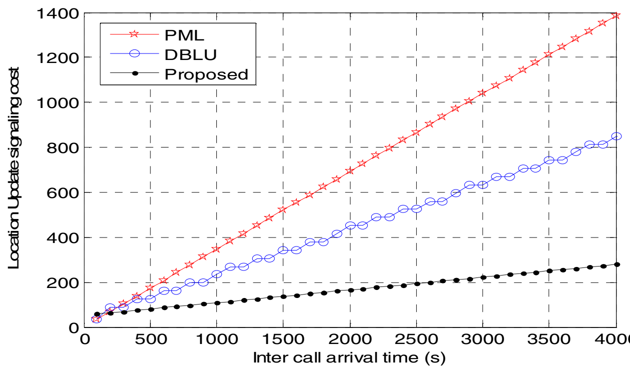

Figure 3: Location update signaling cost between two call arrivals in an OWCAN [12].

We assume that an ONU is an M/G/1 queue having mainly two kinds of traffic arrivals for the upstream direction: data packets and location update signaling packets (i.e. PBU message). An MAG installed on top of ONU's MAC Layer passes those two kinds of packets to the ONU's MAC Layer for uplink transmission through optical backhaul. Furthermore, we consider the arrival rate location update signaling packets are composed of two kinds of location update signaling messages: PBU for the active MTs, rate of which is denoted by λ_1, PBU for the idle MTs, rate of which is denoted by λ_2. And the data packets arrival rate is denoted by λ_{data}. By the assumption of Poisson arrival we may sum the mean arrival rates of those three kinds of traffic to get the total mean arrival rate, which is $\lambda=\lambda_1+\lambda_2+\lambda_{data}$. We know the busy time of M/G/1 is $E[X]=1/(\mu-\lambda)$ [18], where, μ is the service rate of an ONU. Thus the ONU's busy period (i.e. serving time of all kind of packets) can be written as follows for the conventional solutions where Layer 3 location update is required:

$$E_{conventional}[X]=1/(\mu-(\lambda_1+\lambda_2+\lambda_{data})). \quad (1)$$

Then, by eliminating the λ_2 (i.e. arrival rate of the PBUs of idle MTs) we can get an ONU's busy period in our proposed case.

$$E_{proposed}[X]=1/(\mu-(\lambda_1+\lambda_{data})). \quad (2)$$

Therefore, we can conclude the busy time spent by an ONU in proposed and existing solution as follows.

$$E_{conventional}[X]\geq E_{proposed}[X]. \quad (3)$$

From this equation, it can be easily realized that proposed solution minimizes uplink frame dropping probability as in this case the busy time can be less than the busy time of conventional mechanism.

Now, we assess how much energy can be saved by an ONU when our proposed filtering policy (PFP) is used. For evaluating this, we used C++ discrete event simulator developed in our laboratory. To compare these two solutions, we considered real network traffic trace as shown in Figure 4. We can notice from this figure that arrival rate of uplink traffic during the midnight period is significantly lower than the other parts of the day (this comply with the comment "*even the busiest networks in the world still have their on-peak and off-peak periods*" appeared in [22]). This must be highlighted here that we believe arrival rate of traffic and user mobility are two independent events. Then, assuming that an OWCAN is deployed to support for the mobile users travel through a busy highway, it is very likely that there will be very few calls during midnight, whereas, there will be many location update related signaling during that time.

TABLE I. Parameters Used Simulator

Parameter	Value	Parameter	Value
ONU power consumption during sleep mode.	1W [20]	ONU power consumption during active mode.	10W [20]
Transition time (T_t).	2ms [20]	Uplink transmission cycle length.	3ms [3]

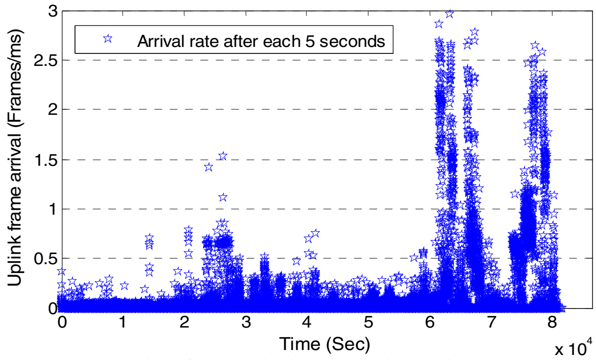

Figure 4: Uplink frame arrival rate variation in throughout a day.

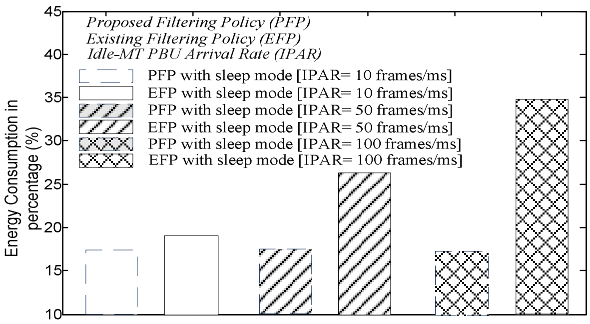

Figure 5: Energy consumed by an ONU.

Table 1 presents the values of the parameters that we used in our simulator. In our simulation, we classify uplink traffic arrival into two groups: (first) data traffic including PBUs of active MTs and (second) PBU of the idle-MTs. In Figure 5 we present performance of proposed solution for 3 different idle-MT PBU arrival rates (IPARs). We compared proposed (PFP) and conventional (EFP) schemes in front of an ONU which does not use sleep mode (always on). In compare to the ONU which is always on (i.e. consumes 100% energy), for IPAR=10 frames/ms 17.31% of energy is consumed when PFP is used; whereas, EFP consumes 18.92% of energy. For IPAR=100 frames/ms, interestingly, ONU using PFP consumes again 17.31% of energy, while ONU using EFP consumes almost double of this energy. In case of PFP, the increment of IPAR does not make any influence on energy consumption of an ONU since PFP successfully filters out PBUs of idle MTs.

V. Conclusion

To support IP mobility in an OWCAN, proposed approaches help to fully utilize the advantage of idle mode in an MT. It is because, an idle MT do not need to wake up to perform Layer 3 location update. Besides, location update signaling cost at mobility management nodes (e.g. MAG) also reduces in the OWCAN. Furthermore, in the optical backhaul energy efficiency and bandwidth utilization is improved. Moreover, when proposed algorithm is applied frame dropping probability in ONUs is also minimized. The unique feature our proposed approach is that we do not require hardware modification. Hence, it is easy to implement in an OWCAN.

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