A hybrid bandwidth allocation algorithm for EPON-WiMAX integrated networks based on auction process

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Abstract
Integration of Ethernet passive optical network and WiMAX technologies is viewed as a great solution for next-generation broadband access networks. In the systems adopting this strategy, weighty bandwidth allocation schemes are fundamental to fulfill the quality of service and fairness requirements of different traffic classes. Existing proposals to overcome the bandwidth allocation problem in EPON/WiMAX networks dismiss collaboration between the self-interested EPON and WiMAX service providers. This study presents a novel EPON-based semi-dynamic bandwidth allocation algorithm to allow the integration process. In the proposed algorithm depending on the auction process, the optical line terminal runs an auction to adequately post the optical network unit bandwidth that distributes the most elevated bidders based on the measurement of the accessible bandwidth. Simulation results demonstrate massive upgrades compared with fair sharing using dual-service-level agreements, limited-service interleaved polling with adaptive cycle time methods, bandwidth allocation strategy using Stackelberg game, and bandwidth allocation strategy using coalition game regarding the quality of service parameters such as throughput and time delay. This will be extremely helpful for optical system upgrading and improvement with minimal effort.

Keywords EPON · WiMAX · DBA · QoS · Throughput · Time delay

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1 Introduction

With the speedy advancement of new organizations reliant on intuitive media applications, broadband access is mentioned due to extensions in Internet traffic. New structures have been moved from the content, and voice-based administrations to the customer-made intelligent interactive media administrations. Voice over IP (VoIP), Video conferencing, video on demand (VoD), online gaming, and high definition television (HDTV) broadcasting administrations will keep growing shortly to realize extending bandwidth necessities. Due to this fantastic improvement, the focal media transmission frameworks are intended to assist new rising applications with gigantic advancement in data transfer bandwidth and limits.

From one perspective, EPON is viewed as a promising solution for the cutting edge fiber-based access method, as it is not just fast, financially savvy, yet versatile. The remote access procedure is additionally steadily redesigning its transfer speed, versatile capacity, and nature of administration quality of service (QoS) support. The new-age WiMAX has now been regulated and passed on. The upsides of bandwidth advantage and portability highlights lead to the incorporated EPON and WiMAX design in Fig. 1 (Lin et al. 2013). EPONs (Wang et al. 2019; Dutta and Das 2019) and IEEE 802.16e/WiMAX (Zhuxian et al. 2018) have shown a noteworthy assurance in the improvement of new-age wired and remote access advances (Tien et al. 2014).

Due to the limited extent of their bandwidth, unwavering quality, adaptability in the arrangement, and low system costs, most Internet service providers (ISPs) view EPONs as a suitable choice in the provision of a backhaul administration for associating different scattered WiMAX base stations (BSs) (Tien et al. 2014; Shyu et al. 2012; Raslan...
et al. 2016; Dias and Fonseca 2012). In any case, EPONs and WiMAX are dependent upon various norms focusing on various system situations. Along these lines, different enormous issues must be settled before they can be adequately coordinated. The noteworthy point in the reconciliation of EPON/WiMAX systems is the booking instrument, which ensures that the heterogeneous progression of traffic (through the Ethernet and the WiMAX) gets a decent amount of the accessible upstream data transmission. Several planning instruments have been proposed to help data transfer in coordinated EPON/WiMAX frameworks (Shyu et al. 2012; Raslan et al. 2016; Dias and Fonseca 2012).

In Shyu et al. (2012) and Raslan et al. (2016), centralized scheduling-based (CS) DBA was proposed to help for the transmission of WiMAX traffic over a coordinated EPON/WiMAX arrangement. In spite of the way that these endeavors eliminate delays, system throughput is diminished, because each sort of traffic has solely a pre-dispensed measure of data transfer capacity, which cannot be reallocated to transmit another kind of traffic in spite of the way that it is not conclusively utilized.

In (Dias and Fonseca 2012), a system that is dependent on game hypothesis was introduced for parleying heterogeneous transmission in an incorporated EPON/WiMAX arrangement.

A bankruptcy game and a bargaining game were utilized to empower each ONU-BS to do intra-scheduling capacities. Although the OLT distributes bandwidth reasonably between the Ethernet and WiMAX, this examination fails to address the issue of QoS. The EPON has the advantages of high bandwidth, low cost, and various services support (Kuo et al. 2012; Chang et al. 2014; Shao et al. 2012).

In this paper, a semi-dynamic bandwidth allocation (SDBA) algorithm is introduced dependent on the auction process, no doubt that the dynamic bandwidth allocation is essential and better than the static bandwidth allocation. Unfortunately, the dynamic bandwidth allocation is time consuming, which affects the delay time and throughput. The dynamic bandwidth allocation is needed in order to determine the demands for each user, but there is no need to repeat the auction process on the bandwidth in consecutive short times. The demand for many regular users does not change quickly or suddenly, and it is approximately constant for each profile. Therefore, in this research, we propose a modified dynamic bandwidth allocation mechanism, which is a mixture between dynamic and static bandwidth allocation “semi-dynamic”.

In the proposed system, the dynamic bandwidth allocation is used in the beginning in order to determine the demand for each user, and the auction process is repeated cyclically each 5 cycles to avoid any mistakes or any unanticipated change in user demands. This saves time and avoids mistakes resulting from repeating the auction process in very short times, such as demand and grant misalignment. Thus, the system will be a static system for 5 cycles and a dynamic system after that, and this is repeated periodically. Therefore, we name the proposed system as a semi-dynamic system. It is demonstrated to be prosperous compared with the existing DBA methods of integration between EPON and WiMAX technologies, namely ST, CO, VOB (Lin and Lin June 2013), IPACT and FSD-SLA (Zheng and Mouftah 2009). The work in this paper is organized as follows. Introduction is presented in Sect. 1. Related work is presented in Sect. 2. The bandwidth allocation of WiMAX and EPON is presented in Sect. 3. The proposed S-Maat algorithm is presented in Sect. 4. Evaluation method and simulation parameters are presented in Sect. 5. Numerical results and discussion are presented in Sect. 6. Section 7 provides the comparison and the choice of the optimum DBA algorithm. Conclusion is given in Sect. 8.
2 Related work

DBA algorithms in EPON can be classified into two categories, centralized (Kramer et al. 2002), and decentralized or hierarchical (Kramer et al. 2004). The framework structure is streamlining well in the centralized algorithms due to the fact that OLT has all capacities of bandwidth allocation. The scheduler and queues located at each ONU cause higher cost in the decentralized algorithms. On the other hand, in the hierarchical algorithm, each ONU reallocates the bandwidth for its interior queue with different sorts of traffic after allocating the bandwidth in OLT. The hierarchical algorithm provides an expansibility and proficient resource allocation in EPON. DBA algorithms can be classified according to the distinct network traffic prediction into two categories, prediction-based and non-prediction-based. Limited bandwidth allocation (LBA) non-prediction algorithm presented in Kramer et al. (2002), and service level agreement (SLA) might indicate the maximum time slot length \( B_{\text{max}} \) which is the upper bound for the time slot length of each ONU. Under the non-uniform traffic, LBA in Son et al. (2004) presented poor performance from the upstream bandwidth perspective.

In order to allocate more granted time slots proficiently and diminish the packet delay, prediction-based schemes have been considered. In the predictive algorithms, to meet the QoS requirements by overhauling the allocated bandwidth, the calculated aggregated traffic has been utilized. In order to avoid over or underestimation, the debase in the network performance according to the longer packet delay, and accurate traffic prediction are highly required. The credit-based bandwidth allocation (CBA) takes a few points of reference transmitted outlines into thought, and when the OLT allocates the upstream bandwidth, it adds a credit into the requirement of each ONU. Some packets do not have to wait for the next grant to arrive. They can be transmitted with the current grant, and the average packet delay can be reduced. Luo and Ansari (2005) presented a prediction DBA algorithm based on LBA with multiple services (DBAM), which executes expectation according to the straight estimation credit. Because the prediction model suffers from serious inaccuracies in the DBAM for some ONUs with high variations in traffic, the performance is deteriorated in non-uniform traffic flow.

In (Standard and for Local and Metropolitan Area Networks Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems – Amendment 2: Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands and Corrigendum 1, 2006) based on the requests from SSs and according to the 802.16 standard, BS is mindful for the uplink bandwidth allocation. Although the standard guarantees the QoS for differential services, the detailed scheduling in algorithms is still unspecified. In (Vinay et al. 2006; Ruangchajatupon and Ji 1979; Wongthavarawat and Ganz Oct. 2003; Kim et al. 2005; Zhang and Harrison 2007), schemes have been proposed with many scheduling mechanisms in order to support real-time and non-real-time algorithms. In this case, the studied schemes can be classified into two categories. The first one is for one-level scheduling schemes (Vinay et al. 2006; Ruangchajatupon and Ji 1979) and the second one is for hierarchical scheduling schemes (Wongthavarawat and Ganz Oct. 2003; Kim et al. 2005). In (Vinay et al. 2006), Vinay et. al. presents a one-level scheduling scheme that uses the Earliest Due Date (EDD) and the Weighted Fair Queue (WFQ) scheduling algorithm in order to deal separately with real-time and non-real-time data. In (Ruangchajatupon and Ji 1979), in order to fit the QoS requirements for algorithms, each traffic sorts its benefit queue and each queue uses different scheduling schemes. One of the advantages in the one-level scheduling is the
low complexity. However, due to the different QoS requirements and the different traffic characteristics, it is hard to deal with all traffic types, well. A hierarchical schedule for different service classes has been proposed by the authors in Wongthavarawat and Ganz Oct. (2003). Detailed execution comparisons have been evaluated in Kim et al. (2005) between hierarchical and one-level schedulers, and this comparison made it clear that the QoS of the hierarchical scheduler is better than that of one-level scheduler. Based on the concepts recommended in Zhang and Harrison (2007), a scheduling solution, such as hierarchical scheduling, has been presented in Hwang (2009).

In the integration process between EPON and WiMAX networks, there are several scheduling mechanisms that have been proposed. QoS-based Dynamic Bandwidth Allocation (QDBA) together with the Prediction-based Fair Excessive Bandwidth Allocation (PFEBA) scheme have been proposed to enhance the system performance in EPONs in Hwang (2009). WiMAX traffic is classified into three priority levels, and then mapped into ONU queues. The three queues with the distinctive needs have been handled in each ONU in the QDBA. An integrated network has been considered to empower information transmission over optical and wireless networks in Yang et al. (2009). This QoS-aware scheme supports bandwidth fairness at the ONU-BS level and class-of-service fairness at the WiMAX subscriber station level. In (Luo et al. 2007), a QoS-aware scheduling mechanism for the integrated EPON-WiMAX network was proposed, but it does not take into consideration the ONU queues. A two-level scheduling scheme for the integrated EPON-WiMAX network was proposed. It takes into thought the queue length. The head-of-line (HoL) delay was proposed in Alsolami (2009).

In (Piquet Dias and Saldanha Fonseca (2012), the scheme uses the corresponding fairness for the transmissions from SSs over the WiMAX channels and a centralized mechanism at OLT for EPON uplink transmission that connects to multiple WiMAX-ONUs. It has the great advantage of being autonomous of the EPON. This encourages the spreading of EPON-WiMAX systems and increments their benefits. A dynamic bandwidth allocation scheme has been considered in Yang et al. (2009) providing a QoS-aware transfer speed dissemination system for EPON-WiMAX hybrid systems. In expansion, a hierarchical QoS-aware DBA (HQA-DBA) scheme has been displayed and applied in both OLT and ONU-BS. This scheme appears to diminish the normal network delay and the packet drop probability. In (Ou et al. Dec 2010a), a DBA framework was proposed to enhance the channel utilization by restricting the signaling overhead. Authors in Moradpoor et al. (2013) studied multichannel PON with a multi-channel wireless access front-end. A scheme based on game theory has been proposed in Coimbra et al. (2013a) giving accentuation to the fairness provisioning. A common drawback of Yang et al. (2009; Luo et al. 2007; Alsolami 2009; Piquet Dias and Saldanha Fonseca 2012; Jiang and M. lei Fu, and Z. chun Le, 2011; Ou et al. Dec 2010a; Moradpoor et al. 2013; Coimbra et al. 2013a) DBA schemes is that they disregard the time of the coordination as a basic factor affecting the surveying execution. A prediction-aware DBA scheme has been proposed in Sarigiannidis (2015), assuming that FiWi networks consist of an asymmetric 10G-EPON and WiMAX base stations in the front end. The reader is recommended to review the research in Sarigiannidis et al. (2015) for more DBA schemes and algorithms.
The bandwidth allocation of WiMAX and EPON

Both WiMAX and EPON use a non-exclusive survey/demand/award component; that is, a central station (OLT or WiMAX BS) surveys a far off-station (ONU or SS) on bandwidth demands. The focal station at that point awards bandwidth. The high similarity empowers the mixture of bandwidth designation and QoS support in the incorporated access structures. In any case, there is an individual difference in specific nuances. EPON upholds QoS in a DiffServ mode, under which bundles are portrayed, grouped, and set aside in precedence queues. Then, again, regardless of the way that the services of WiMAX are ordered to help various degrees of QoS, WiMAX is considered a connection-oriented technology, which primarily seeks after an integrated service (IntServ) model (Bhatt 2017). Subsequently, for incorporation, a fascinating approach is the best approach to make possible changes between (DiffServ) and (IntServ) services. Also, it is moreover exquisite to perceive how the end-to-end QoS can be upheld after these two frameworks are incorporated. As an issue of hugeness, we should stress on the bandwidth allocation features of WiMAX and EPON systems. WiMAX demands bandwidth for every association premise, yet assigns bandwidth on a per-SS basis (Sari-giannidis and Nicopolitidis 2016). Upon being granted bandwidth, each SS settles on nearby choices to allocate the bandwidth and time tables for parcel transmission for each association. It supports two sorts of bandwidth allocation modes: unsolicited and upon request. WiMAX groups the information traffic into five QoS levels extending from undesirable grant service (UGS) to best effort (BE) (Hussain et al. 2018; Ou et al. Dec 2010b; Coimbra et al. 2013b; Runa et al. 2019; Hatem et al. 2019; Kim 2018).

Proposed S-Maat algorithm

It is an EPON-based DBA utilizing the auction process. In this strategy, OLT is answerable for auction process, which can react in a successful way to bandwidth demands from ONUs compared with their needs and the last time they are stand-by to get their requested bandwidth. Besides, the auction cycle repeats itself once every five cycles of the bandwidth allocation process performed by mathematical iterations. We choose five cycles, which achieve remarkable results in time delay and throughput, simultaneously. Figure 2 represents the different numbers of cycles with respect to time delay and throughput performance. We compared an EPON based on DBA using auction theory with Maat. In this method, OLT is responsible for an auction management, which can respond in an effective manner to bandwidth requests from ONUs relative to their priority and the maximum time they can wait to receive their requested bandwidth (Maher et al. 2019). The S-Maat is a modified dynamic bandwidth allocation algorithm that is a hybrid mixture of dynamic and static bandwidth allocation “semi-dynamic”.

The general strides of this algorithm, which depends on the auction process, are summarized as follows and illustrated in Fig. 3.

First step: Reporting the process by OLT for the allocation of bandwidth to the ONUs and presenting the underlying states of the auction of the ONUs.

Second step: Analyzing the introductory auction conditions by the ONU that sends the bandwidth demand boundaries to the OLT. These parameters include the most magnificent holding uptime of an ONU to get a service, alluring bandwidth, and priority.
Third step: Investigating the obtained demands from ONU s, figuring the offer qualities followed by the determination of the best bidders and producing sub-records from the first rundown of the ONUs. We can figure the offered qualities by analyzing the received requests from ONUs and calculating the bid values followed by the selection of the best bidders and the generating sub-lists from the original list of ONUs.

Fourth step: Assigning bandwidth to the most noteworthy bidder ONUs, and managing the utilization of the bandwidth.

Fifth step: Recurrence of the entire cycle from the first step once every five cycles of bandwidth allocation process.

The overall process is illustrated schematically in Fig. 4.

Announce by OLT:
Announcing of the auction by OLT in order to allocate the bandwidth of the ONU and transmit the initial conditions of the auction to the ONU is performed. The initial conditions should include:

- The deadline for accepting ONU requests.
- The maximum available bandwidth accessible to OLT.

Fig. 2  a Comparison between throughputs for different numbers of cycles from the iteration process. b Comparison between time delays for different numbers of cycles from the iteration process.
The response time.

*Submitting bids from ONU:*

Examinations of the initial auction conditions by the ONUs and transmission of the bandwidth requirement parameters by the ONUs to the OLT are based on parameters such as the maximum waiting time of an ONU to receive a service, the desired bandwidth and the priority. ONUs review the above conditions, and this is followed by submitting their parametric bid to participate in the auction managed by OLT.

*ONU requests:*

Here, we mean mainly the bandwidth demand submitted by the ONU, which is represented by the bids from the ONU in the auction process, followed by the selection of the best bidders and the generation of a sub-list from the original list of ONUs.

*OLT computes all bids from ONU.*

Winners are selected from computed bids based on the maximum available bandwidth.

Publish list off all Requests.

Allocating the bandwidth to the highest bidder ONU and monitoring of bandwidth usage are performed. OLT checks all requests received to participate in the auction. It firstly analyzes the state by asking if an ONU is sending a request. Then, if the above condition is confirmed, all ONUs selected to participate in the auction are listed, assuming that they are not receiving any service. The amount of bid is then calculated based on the basis of the first-price auction theory. Then, a certain number of ONUs are selected to be the highest bidder in the auction, and they are allocated bandwidth under the following condition:
Fig. 4 Schematic diagram of the overall process in the S-MAAT algorithm
where:

- \( B_{\text{OLT \ Available}}(t) \) is the available bandwidth for the OLT.
- \( B_{\text{Req \ ONUw}}(t) \) is the requested bandwidth from the winner ONUs in time \( t \).

Is there any busy ONU?:

Busy ONU refers to the ONU, which does not participate in the bidding process for any reason. So, we should take it into consideration in creating our bidders lists.

(List 1 consists of all requests and List 2 consists of List 1 and new requests from occupied or busy ONUs).

\( BW \text{ available } \geq BW \text{ used till now:} \)

At this step, we must check that the bandwidth is more than or equal to all demands or not.

Select number of winners with respect to computed bids and maximum available bandwidth and allocate bandwidth:

In this stage, the algorithm allocates the bandwidths.

Publish remaining ONUs list to be able participate in the next round of auction:

For all busy ONUs, the algorithm publishes the ONU lists to be able to participate in the next round of auction.

## 5 Evaluation method and simulation parameters

In this section, the mathematical models used to calculate the delay/throughput for different DBA algorithms in the integration process under test are extracted from the literature. The evaluation method is based on (OPNET/C++) calculation for these algorithms/models. The parameters are applied to the numerical models. A comparison between DBA algorithms concerning throughput and time delay in the integration process between EPON/WiMAX is presented, targeting the best choice to enhance the integration process, algorithm performance, and IPACT delay, which is calculated as follows:

\[
D_{\text{FSD-SLA}} = D_{\text{Cycle-Time}} + D_{\text{GRANT}} + D_{\text{SLA}}
\]  

where,

- \( D_{\text{POL}} \): time between the packet arrival and the next request sent by the ONU.
- \( D_{\text{GRANT}} \): time interim from an ONU solicitation for a transmission window until the beginning of the timeslot in which this casing is to be sent. This deferral may traverse numerous cycles, contingent upon the number of structures existing in the line at the time of the fresh debut.
- \( D_{\text{QUEUE}} \): delay from the earliest starting point of the timeslot until the start of the frame transmission. This postponement is equal to half of a space time and is not significant compared to the previous two fragments.

\[
D_{\text{IPACT}} = D_{\text{POL}} + D_{\text{GRANT}} + D_{\text{QUEUE}}
\]
D_{Cycle –Time}: greatest time cycle length. The scheduler at the OLT may plan bandwidth for the most fabulous time of T in one emphasis on schedule.

D_{Delay GRANT}: time interim from an ONU solicitation for a transmission window until the beginning of the schedule opening in which this casing is to be sent. This deferral may traverse numerous cycles, contingent upon what number of frames in the line at the hour of the new arrival.

D_{SLA}: checking delay of the essential and optional SLA requests.

Maat.

Delay:

\[ D_{Maat} = D_{delay Announce} + D_{delay Auction} + D_{delay Allocation} \]  (4)

where,

D_{delay Announce}: time to commence the auction process and present the parametric offer.

D_{delay Auction – Process}: time that the auction procedure is running.

D_{delay Allocation}: time to distribute the bandwidth to the most noteworthy bidders.

Throughput rate_{TR} = \frac{\text{Info}_{Total–\text{Recv}}}{\text{Time}_{\text{Take–To–Recv}}} \]  (5)

\text{Info}_{Time–\text{Recv}}: time for the cooperative data conveyed.

\text{Time}_{\text{Take–To–Recv}}: time taken to accomplish recovery (Table 1).

The simulation parameters used are extracted from the published work in this field (Mohamed et al. 2016).

6 Numerical results and discussion

The throughput performance and time delay for the DBA algorithms under evaluation are presented to determine the ideal DBA algorithm that accomplishes a noteworthy throughput and time delay performance among all DBA algorithms under assessment in the integration process between EPON/WiMAX.

A. Throughput Performance

In this section, the parameters and their corresponding values are applied to the mathematical models to generate the following throughput performance for the DBA algorithms under evaluation.

Figure 5 represents the network throughput performance versus offered load for different algorithms. Due to the high bandwidth demand required by modern life applications and personal digital assistants (PDAS), this work will focus on the high offered load (i.e., 0.8–1 Gbps) scenario, and this reveals superiority of the S-Maat algorithm.

Table 2 represents the order of DBA algorithms according to their throughput performance as a function of the offered load as extracted from Fig. 5.

B. Time Delay Performance

The methodology of study of throughput performance is repeated here for time delay performance. Figure 6 presents the time delay performance versus the offered load.
Table 2 presents the order of DBA algorithms according to their time-delay performance as a function of the offered load as extracted from Figs. 6, 7, 8, and 9.

7 Comparison and selection of the optimum DBA algorithm

Based on the illustrated results in Figs. 5, 6, 7, 8, and 9, the target now is to compare between the four optimum DBA algorithms that achieve acceptable throughput and time delay performance simultaneously for more processing. Two crucial observations about the proposed algorithm can be extracted from Table 2. Firstly, it is difficult to obtain a

| Parameter                                      | Value              |
|------------------------------------------------|--------------------|
| Number of ONUs                                 | Around 16          |
| Distance between OLT and ONU's                 | 20 km              |
| Packet size                                    | 15,000 byte        |
| Ethernet overhead bits                         | 304 bits           |
| Upstream bandwidth                             | 1 Gbps             |
| Maximum cycling time                           | 2 ms               |
| Buffer size                                    | 10 Mbyte           |
| Two-way fiber delay                            | 200 μs             |
| Guard time                                     | 5 μs               |
| Traffic type                                   | Poisson Distribution|
| IPACT condition                                | Fixed              |
| Bit rate for ONU to OLT                        | 5 to 57.5 (Mb/s) Mbits/s for Maat & S-Maat |
| Other algorithms                               | 62.5               |
| Window size for report message (Byte)          | 64                 |
| Request message size (bits)                    | 570 bit            |
| Maximum transition window (Packets)            | 10 for Maat & S-Maat|
clear order for DBA algorithms that achieve remarkable throughput and time delay performance, simultaneously, because the DBA algorithms that produce a noteworthy throughput performance have lower quality for time-delay performance and vice versa. Secondly, the DBA algorithms in time delay and throughput performance are very close, which makes the selection operation more difficult. However, we can try to extract the optimum DBA algorithm that can achieve acceptable rather than remarkable throughput and time delay performance.
Fig. 7 Performance comparison from 0.2 to 0.55 Gbps

Fig. 8 Performance comparison from 0.4 to 0.75 Gbps

Fig. 9 Performance comparison from 0.65 to 1 Gbps
performances, simultaneously. Accordingly, the selection will be the proposed S-Maat algorithm. Table 3 provides the percentage of enhancement in the time delay and throughput for the different offered loads.

8 Conclusion

A novel and successful auction semi-DBA algorithm has been proposed utilizing the coordinated WiMAX/EPON innovation with a dynamic determination of ONUs by OLT. This strategy exhibits significant upgrades in diminishing packet time delay and enhancing throughput with limited service IPACT, FSD-SLA, bandwidth allocation strategy using coalition, bandwidth allocation strategy using Stackelberg, Maat, and VOB methods. This study could be utilized for considering and structuring the cellular parametric offer calculation, running settled auctions for better execution and investigation of (Fi-Wi) connection with Long-Term Evolution Advanced (LTE-A) for accomplishing an improved QoS and characterizing the distribution in EPON and LTE.

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