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Bidirectional multi-optical line terminals incorporated converged WSN-PON network using M/M/1 queuing

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ABSTRACT

Wireless Sensor Networks (WSNs) have an assortment of application areas, for instance, civil, military, and video surveillance with restricted power resources and transmission link. To accommodate the massive traffic load in hefty sensor networks is another key issue. Subsequently, there is a necessity to backhaul the sensed information of such networks and prolong the transmission link to access the distinct receivers. Passive Optical Network (PON), a next-generation access technology, comes out as a suitable candidate for the convergence of the sensed data to the core system. The earlier demonstrated work with single-OLT-PON introduces an overloaded buffer akin to video surveillance scenarios. In this paper, to combine the bandwidth potential of PONs with the mobility capability of WSNs, the viability for the convergence of PONs and WSNs incorporating multi-optical line terminals is demonstrated to handle the overloaded OLTs. The existing M/M/1 queue theory with interleaving polling with adaptive cycle time as dynamic bandwidth algorithm is used to shun the probability of packets clash. Further, the proposed multi-sink WSN and multi-OLT PON converged structure is investigated in bidirectional mode analytically and through computer simulations. The observations establish the proposed structure competent to accommodate the colossal data traffic through less time consumption.

1. Introduction

Wireless Sensor Network (WSN) is a self-governing network of sensor nodes with limited computing and communication capabilities, where the sensed information is aggregated at a sink node. The importance of WSNs increases day by day, as these networks have a strong perspective in many areas such as military, civil, environment monitoring, and video surveillance. The applications such as video surveillance generate massive data; therefore, multiple sinks are required to handle such colossal information together with covering the vast geographical areas at minimal energy consumption. Further, a fixed access network topology with high spectral efficiency is required to backhaul such immense sensed information of WSN networks, which make it accessible to the distinct receivers for further processing. The Passive Optical Network (PON) is proposed as a next generation access technology in earlier research work to backhaul such wireless networks. The PON technology is a point to multipoint system and serves multiple subscribers at endpoint through a single optical fiber. The PON consists of an Optical Line Terminal (OLT) which communicates with various Optical Network Units (ONUs) via an optical fiber cable, with multiple benefits over other available access networks such as higher bandwidth, ease of deployment and long distance communication [21]. The convergence of WSNs and PONs can be achieved in various ways such as single WSN-single PON (Type 1), multiple WSNs-single PON (Type II), and multiple WSNs-multiple PONs (Type III). The Type I network, the WSN network may have one or more than one sink node within the network; whereas the Type II network may have two or more than two WSNs in which each WSN may contain one or more than one sink. Further, Type III architecture is deployed for wide area coverage, and the combination of the above discussed approaches. It is desirable to explore the modeling of Type II and Type III networks, not only to prolonge the transmission links but also to handle the massive sensed information. Furthermore, the queuing models play a major role in modeling of such converged optical and wireless networks. The queuing models are also named as waiting line models where the input entity (data packets) unites in a queue to acquire some services, depending upon the requirements, from the server. The entities arrival rate and service rate to the entities are supposed to follow some non-deterministic distribution, for instance, Poisson distribution, exponential distribution etc. In the proposed work, the authors used Poisson

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distribution for data arrival estimation and the later is used to distribute the sensed data for OLTs to ONUs. The demonstrated work is presented as follows. Section 2 described the related earlier reported work. The proposed work is presented in Section 3 followed by the system description and performance evolutions in Section 4. The conclusion drawn from the observations is depicted in Section 5.

2. Related work

In this section, the earlier reported work on the modeling of WSNs, PONs and the convergence of these two technologies has been presented. To maximize the lifespan for a WSN, an M/M/1 queue theory model has been presented in [1], while the optimization for the deployment of non-beacon-mode 802.15.4 has been reported in [2]. The Packet Buffer Evolution Method explored for WSN by correlating packet lengths of two different nodes using a queue theory [3]. The reported work bestowed the estimations for the overcrowded state within the WSN network for the receiving of authenticated and the successful arrival of data by expanding the WSN queue model as a holding node. Further, the M/G/1 queue model has been introduced to reduce the overloaded traffic of a movable sink [4] and to explain the scheduling of wake up time to improve the QoS as well as decreasing the node power utilization [5]. Subsequently, another proposal of an M/M/1queue model is reported to carry out the average delay estimation for data packets passed by sensor node and validated the results by taking the real time data of Huoerxinhe Coal Mine [6]. An analysis for path delay in large scale WSN particularly for temperature monitoring has been addressed by [25]. The iterative approximation algorithm based on open queue network model is reported which analyzes the path delay behavior for large scale WSN in term of end to end delay for pre-preferred nodes paths and average queuing networks delay. The outcomes of proposed method are helpful to find out the optimal and assistant path for data transmission within the WSN. Another M/M/1 queue theory based analytical model is demonstrated for energy utilization of cluster based underwater wireless sensor nodes [7]. Further, GI/M/1-type with N-policy queue theory is used to investigate the transient departure behavior of data packets from sensor node of WSN [26]. This queue based mathematical model is designed to minimize energy consumption of WSN by controlling the activation of transmitter/receiver according to define threshold number of packets pending in queue buffer. The transmissions of data packets take place only when defined threshold value approaches for data packets in queue buffer. To study this analytical model the data packet departure of one node is considered as arrival rate for other node. A mixed double transform distribution for departure process is investigated using embedded Markov chain, renewal theorem the continuous probability law and linear algebra. Earlier, GI/M/1/K-type queue model with N policy is presented [27] to analyze the transient behavior of queue delay and set the guideline to define the threshold value in case of high legality (fire detection) and less imperative (traffic monitoring) WSN data for achieving optimal power management. The diverse modeling techniques for PONs have been deliberated in [8–10]. All these above-discussed earlier reported work investigated the progress of modeling of WSN- and PON-networks that dealt with challenging issues of WSNs and the spectral strength of PON technology.

To address the backhaul problem of WSNs with PON, only few works have been reported. The convergence of WSN-PON has been analyzed for Synchronized Latency Secured MAC protocol where Personal Area Network Coordinator acts as an OLT to connect the Cluster Head (CH) as an ONU by taking care of the energy utilization of sensor nodes [11]. A demonstration which shows the capability of PON as a backhaul access network for 802.16 network using DBA algorithm is reported in [12]. This DBA scheme takes into consideration the explicit characteristic of the congregated network to facilitate smooth data broadcasting between optical and wireless networks, and back-to-back differentiated service to consumer traffics of various QoS (Quality of Service) requirements. This QoS-conscious DBA method maintains bandwidth equality at the VOB (virtual ONU Base station) level and class-of-service fairness at the 802.16 subscriber station level. The station fairness signifies that bandwidth shall be decided for all VOB/SS as uniformly as possible with no compromise to QoS requirements and is also imperative to VOB since a VOB has a entire 802.16 network to be served.

Another queue based convergence model of one-sink WSN with one-OLT PON the packet's uplink is examined by projecting a converged network composed of a PON and WSNs. Further, an analytical approach using two M/M/1 queue in tandem is reported which describes the influence of PON- and WSN- parameters over the performance of the whole congregated network structure [13] and is extended further for uplink data packet transmission within a multi-sink WSN with single-OLT PON congregated network architecture with multiple priorities [14,15]. The author claimed better performance with priority based multi-sink WSN using single-OLT PON approach.

The work is further extended to demonstrate Type III converge networks by demonstrating a new DBA algorithm, named as adaptive limited dynamic bandwidth allocation, for a multi-OLT PON (ALDBAM) [23]. The projected customized ALDBAM algorithm offers lesser packet delay with higher bandwidth utilization, elevated upstream effectiveness, and higher throughput than the standard DBA techniques. Furthermore, a novel network structural design intended for a PON- based open access network (OAN) is also demonstrated in which each optical network unit (ONU) will be shared by each and every service providers and in the central office, multi- OLTs will be linked to handle the data packets of various service providers [24]. Further, a Radio over Fiber (RoF)-WSN architecture is also proposed [16] and investigated to improve the system waiting-time and energy consumption of entire network within the environment by incorporating an appropriate number of remote antenna units. Another hybrid fiber-wireless sensor network is demonstrated experimentally that uses the existing gigabit passive optical networks (GPON) as a backhaul to WSN in which a single-head sensor node collects the WSN data and transfers it to the fiber based single-OLT PON [17].

The above discussed converged network models are based either on single-sink WSN with single-OLT or multi-sink WSN with single-OLT, whereas, a little effort has been initiated to demonstrate Type III converge networks i.e. multi-sink WSN and multi-OLT PON network. The reported work is also limited to downstream transmission only. The work demonstrated in this paper is an extension of earlier reported Type III converge uplink network. In this work, a bidirectional multi-sink WSN and multi-PON converged network infrastructure is modeled and discussed analytically. Further, an investigation is carried out to show that the proposed converged infrastructure can support existing bandwidth allocation schemes with better performance than Type I and Type II converge networks in terms of the time cycle, average time delay, number of arrival packets, upstream and downstream transmission and bandwidth utilization.

3. Proposed work

To backhaul the massive sensor entity in conjunction with the prolonging of the transmission link with high spectral efficiency, an efficient converged network is today's necessity. In view of that a multi-sink WSN and multi-OLT PON converged infrastructure is proposed as an extension of single-sink WSN and single-OLT PON [13]. The proposed converged network is demonstrated with single or multiple WSN networks where each WSN network is consigned to a single optical sink (OS)/ONU and OLT. Additionally, it is assumed that the multiple WSN structures will never exchange data between each other. It implies that once the destination address of a sensor node is determined, it remains same throughout the transmission within the converged network. Otherwise, it augments the collisions. The work is further extended to realize a bidirectional converge network in which the up-streaming is