Overview of Fronthaul Technologies and the DBA Algorithms in XGPON-Based FH Technology in CRAN Architecture in 5G Network

Theresal Thangappan and Brintha Therese

Abstract The cloud radio access network or C-RAN is the vital technology involved in the fifth-generation (5G) radio access network. It is a centralized, cloud computing architecture for radio access network which is allowing many remote radio heads (RRHs) to connect to a centralized baseband unit (BBU) pool. The fronthaul (FH) approach has evolved due to significant difficulties in 5G transportation technology. Different fronthaul techniques were discussed in this paper, as well as the motivation to achieve the optimal FH solution through a time division multiplexing passive optical network (TDM-PON), and also an overview of the dynamic bandwidth allocation (DBA) algorithms in fronthaul technologies based on TDM-PON and their 5G network CRAN architecture characteristics.

Keywords Fronthaul · CRAN · TDM-PON · DBA

1 Introduction

High bandwidth user applications, such as the Internet of things (IoT), social networking sites, and video conferencing, have substantially evolved cellular communication paradigms. As the present technology (4G) is similar to the Shannon limit [1], the development of next-generation technology (5G) is essential to provide various services. The 5G technology aims to provide a data rate that is five times (i.e., >20 Gbps) more than the wireless system, and the latency is less than 1 ms [2]. For reaching the milestone of 5G technology, different techniques are in use. They are heterogeneous small cells, multiple inputs, multiple outputs (MIMO), energy-efficient antennas, non-orthogonal multiplexing scheme, sparse code multiple access schemes, and 3D beamforming and millimeter waves (mm). These are being researched upon as all the research organizations have extended their support for the 5G standards. The following methods need to be employed by mobile network operators (MNO) to develop the network capacity. The deployment of maximum cells

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[3–6] and the use of advanced radio access technologies [7, 8] will achieve the use of additional spectrum. In the end, the most suitable solution for network capacity enhancement is the small cell method [6, 9, 10]. CRAN [11–15] used for the 5G network because of the benefits such as site installation process, cost-efficient, and need of the low power [16–18]. Hence, CRAN is an eminent method when immense numbers of remote radio heads (RRHs) are required to increase the network capacity [19]. CRAN introduces some changes in the 5G layer known as the fronthaul (FH) solution. The FH solution links the RRH to the BBU directly.

2 Centralized RAN Architecture

In the abbreviation CRAN, "C" refers to either cloud or centralized. CRAN divides the functions of traditional base transceiver station (BTS). The radio still functions through the RRH and remains either in the BTS capsule or at the radio site. During the baseband process's function, the BBU has been partially or fully moved from the cell to the COs (central office) at a common shared site and becomes the reason for developing a new RAN interface called FH. Therefore, CRAN is implemented through three network elements, i.e., FH interface, BBU, and RRH.

The sole purpose of RRH is to transmit and receive digitized radio signals. Since the functions of RRH are simple, the hardware that needed to carry out these tasks is cheap and makes the overall deployment cost of RRH less in a widespread area. The baseband unit performs three complex functions: resource allocation, resource scheduling, and baseband (radio) signal processing function. The tasks performed by BBU are complex, and the hardware used to perform those functions is a bit expensive. So, to reduce the overall maintenance cost of the network and CAPEX/OPEX, BBUs are implemented in a centralized manner.

The Metro Ethernet Forum (MEF) firstly describes the term FH as a network interface between centralized BBU and RRH. BBU and RRH will be connected via optical fiber using radio over fiber (RoF) technology. The RoF here falls into two categories, digital and analog RoFs. In these, digital RoF (DRoF) is more prominent and also a standardized one. It can also transmit signals (wireless) with less degradation [20], whereas analog RoF (ARoF) is not standardized [21]. Common Public Radio Interface (CPRI) is a widely used digital RoF interface and several telecommunications vendors [5, 12, 22–24]. Studies show that the most complex part of CRAN architecture is fronthaul since it ruins CRAN's overall performance and capacity. FH also makes the deployment cost of CRAN worse. Therefore, it should be built strategically [25, 26]. Copper, microwave, optical fiber, optical free-space contact, and mm waves are used to achieve the FH interface [12]. Out of all these, the optical fiber is considered the most preferred physical medium for FH because of its effective handling against low latency in gigabit connections [5, 27–30]. Figure 1 shows the CRAN architecture.

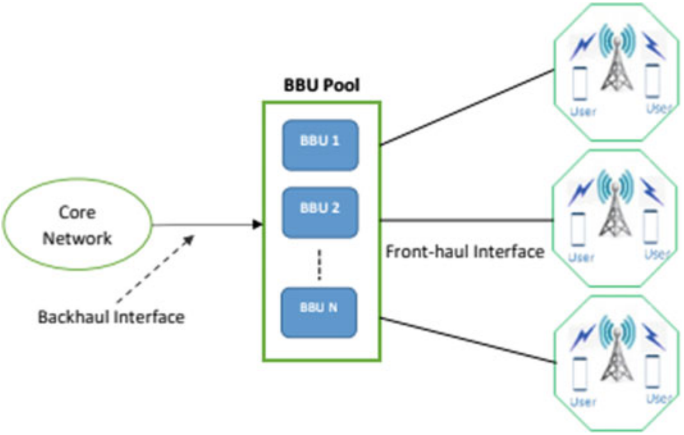

Fig. 1 CRAN architecture

3 Fronthaul Network Technology

Each fronthaul network will have its mix of challenges depending on deployment strategy, geographical area, number of sites, and RAN technology. It is essential to evaluate each deployment scenario and apply the right mix of technologies and solutions. Operators have several technologies that can be applied for the fronthaul use case, each comprising its advantages and disadvantages.

1. Wireless fronthaul solution:

Wireless technology is a feasible fronthaul transport, resulting in remarkable evolutions in telecommunication networks. It inherits the following advantages: simplicity, easy deployment, scalability, support roaming, efficient collaboration and cost-saving. It is a complement solution for fiber-based fronthaul solution, and because of its susceptibility to channel condition, it is suitable to implement for short range. The current wireless technology can adopt a few CPRI interface options, and that limits the bandwidth. Some of the promising wireless solutions like millimeter wave (MM-W) and Wireless Fidelity (Wi-Fi) are engaged within the fronthaul [31–33]. Wi-Fi network faces the limitation in coverage and mobility even though it provides sufficient data rates, and this problem might be reduced by Wi-Fi mesh network [31, 34].

2. Wired fronthaul solution:

Wired technologies' merits are less interference, maximum coverage, less latency, reliability, and security. Due to these advantages, the wired system can stand like a wireless system. Dark fiber, WDM-based solution, WDM-PON, WDM/optical transport network (OTN), and Ethernet are examples of fronthaul technology in wired systems. The superior wired fronthaul technology which is suitable for the solution discussed in the subsection.

a. Dark fiber solution

Dark fiber solution is considered an attractive and most comfortable deployment solution with low latency, as there is no need for transmission components between the BBU pools and the RRUs. It is a point-to-point solution; therefore, it lacks network security and is not suitable for 5G services, requiring high reliability. It also requires a high amount of fiber resources, making the deployment cost high and is a primary limiting factor.

b. WDM-based solution

WDM-based fronthaul solutions are classified into active and passive methods. It is beneficial for fronthaul solutions which need low latency and high data transmission rate. The active techniques provide a robust network with suitable flexibility, and with an optical amplifier, the system extends significantly, and it needs a power supply for the operation. The passive method depends only on CPRI multiplexing and demultiplexing since it uses passive components with no need for power supply and battery backup [31–35]. In passive methods, the switching granularity depends on the spectrum or time slot. The active method depends on packet or frame switching. Even though active methods provide good configuration flexibility, its power consumption is complicated. [36].

c. WDM/OTN

In WDM/OTN, the fiber capacity is boosted by adding multiple channels in a shared fiber to achieve multiplexed and transparent transmission of a signal through the fronthaul to link numerous sites [31, 33, 35]. The in-phase and quadrature component (I/Q) data encapsulated by the OTN frame and then multiplexed with WDM wavelength. This wavelength is used for routing the frame to the destination [36]. This method has features like low latency, high bandwidth, security, scalability, and reliability despite fiber resources. WDM transport network does not require a power supply, but it is necessary for wavelength translation and active management [31, 33, 35].

d. Packet/Ethernet-based Fronthaul

Packet technology in Ethernet-based technology emphasizes the statistical multiplexing features and helps achieve traffic convergence and enhance bandwidth usage. The most efficient Ethernet-based fronthaul option is to convert CPRI into eCPRI in the RAN domain. This approach leverages their CPRI data streams' baseband processing and converts the time domain signal to the frequency domain. The benefit of the CPRI to eCPRI conversion is that it drastically reduces the capacity required for Ethernet fronthaul by scaling traffic with used antenna bandwidth and removing the constant bit rate of the CPRI traffic. The conversion process will not add any additional latency in the fronthaul transmission, enabling more extended macrosites to CRAN hub site distance compared to RoE and greater flexibility in building the fronthaul network. Combining CPRI to eCPRI conversion with packet aggregation at the antenna site is the most efficient approach. The fronthaul capacity demands are reduced by 60–80% depending on radio configuration compared to other technologies such as traditional CPRI or mapping of CPRI utilizing RoE.

e. PON-Based Solutions

The intensive bandwidth traffic required for 5G and beyond network is not satisfied by the fiber-based and P2P Ethernet because of ultra-dense network deployment and highly network resources in the 5G network. The PON system reduces the number of interface and site space, and system power can also be saved [37]. PON technology has both WDM and TDM techniques used to improve the capacity and efficiency, and according to these techniques, the PON system is classified into WDM-PON and TDM-PON. TDM-PON provides higher bandwidth for different services even though available resources are limitedly delivered to the end user. But this is overcome by assigning one wavelength to the per user in WDM-PON high data rate and well secure because of the P2P channel and useful for the long-reach application. The WDM-PON does not recommend for fronthaul and backhaul technology.

Numerous optical solutions for 5G fronthaul technology have been proposed in a lot of literature. Depending on the following factor-like bandwidth requirements, latency, resource availability, business type, and deployment method, the deployment choice has been chosen from the following FH technology in the 5G network, i.e., P2P fiber access, OTN, WDM, PON, and carrier Ethernet [38, 39]. PON performs other solutions because of its high bandwidth, low installation and operational cost, and coverage. The PON system also uses the existing fiber cables or optical distribution networks (ODNs), optical network units (ONUs), and optical line terminal (OLT) for FH solution, even if it provides both wired and wireless services to the customers [40, 41]. Finally, PON is solemnly considered as a solution for FH technology as it effectively uses the fiber sources of existing fiber to the home (FTTH) [42, 43].

4 TDM-PON-Based Fronthaul Technology in CRAN

OLT, ONUs, and ODN have composed TDM-PON-based fronthaul technology. The OLT, which is located at the CO, is placed near BBU. The ONU, which is located beside the customer, is placed near to RRU at base stations. One OLT is capable of linking more than one ONUs through the passive splitter. TDM-PON needs a single wavelength, so it is a simple and cost-efficient solution, but the latency issue remains persistent in the FH solution. The following are the two factors conventional DBA and window size will be used to improve the latency of TDM-PON [44], for monitoring ONU registration and its activation time by using window size. In TDM-PON, many researchers are taking initiatives to provide the low-latency TDM-PON-based FH technology in the 5G network to prevent the collision between the ONU's simultaneous transmission by using DBA and providing the time slots to ONUs in each cycle to increase the overall latency performance. Figure 2 shows the TDM-PON-based FH technology for CRAN architecture.

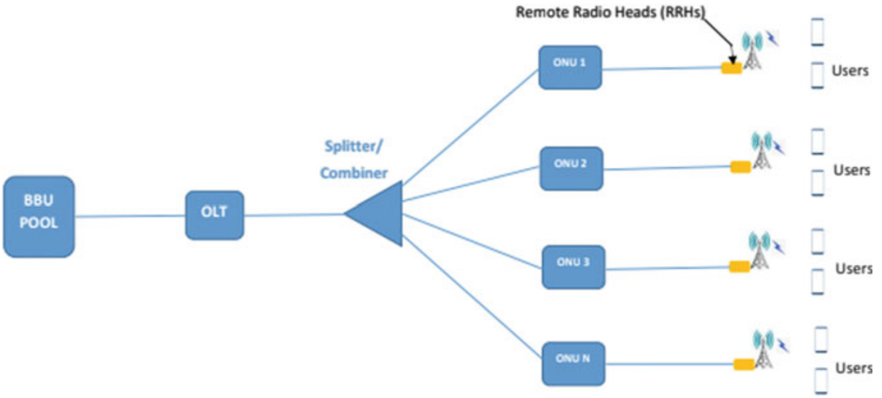

Fig. 2 TDM-PON-based FH technology for CRAN architecture

5 DBA Algorithm in XGPON-Based FH Technology

The latency concerns about the TDM-PON-based fronthaul technology have been proposed and studied widely among many papers. The author [45] of the article has depicted the optimized TDM-PON concept, which can be implemented for transparency optical transport of lower latency with constant bit rate data. The mathematical models analyzed that it was based on queuing theory and has achieved one-way latency, which is less than 250 μs. In paper [46], the author has presented the CPRI concept over the Ethernet-based TDM-PON. The delay jitter and the latency could be reduced using the IQ compression technique concept around 100 μs for a particular compression ratio. Paper [20] introduces the mobile DBA algorithms used to reduce the front haul latency by using mobile scheduling information from BBUs for the bandwidth allocation. It has achieved less than 50 μs by utilizing a fiber length of 10–20 kms. This approach needs a connection for the transfer of information from BBUs to OLT. Paper [47] introduces simple statistics functions in coordination with the fixed bandwidth allocation (FBA) to dynamically provide the data rate for the fronthaul transmission over G_EPON. This method relies on the periodical estimation of RRH traffic; therefore, it cannot capture low-scale variation in fronthaul traffic at each RRH.

In paper [48], the author reduced the DBA cycle length by lowering the DBA grant time to minimize the upstream latency of 10G EPON. This technique is not suitable for ITU TDM_PON as it is neither synchronous not has a fixed frame length as that of ITU TDM PONs. ITU PON [49] has fixed frame length and has frame support fragmentation that helps reduce the latency lower than IEEE PONs [50]. The above reasons require a lot of research work motivated based on fronthaul using XGPON.

Round robin DBA/RR DBA algorithm is the most straightforward algorithm that uses DBA compatible with the XG-PON model, and it is the first algorithm for using the fronthaul by XGPON [51]. RR-DBA uniformly allocates the bandwidth, which is less than or equal to a predetermined value circularly to all T-Conts. Good delay performance, but the utilization of upstream bandwidth under busty traffic conditions, is very poor and has not satisfied the 300 μs latency needed for the front haul technology. In group assured Giant DBA [52], which helps optimize XG-PON to transport backhaul traffic, and it is concluded that either RR-DBA or the gGAINT fulfills the latency requirement for the fronthaul. The gGAINT algorithm can assign group-assured bandwidth by sharing the unutilized data from individual assured bandwidth with other T_Conts of the same group and failed to fulfill the latency requirement for fronthaul technology. In optimized RR DBA, a modified RR DBA version. In this algorithm, firstly, it will find the total extra bandwidth from each upstream cycle, and then it will redistribute it to the heavily loaded T-Conts in the next transmission cycle. The lightly loaded T-Conts excess bandwidth will be utilized by heavily loaded T-Conts to eliminate the problems faced in the RR algorithm and satisfy the latency requirement for fronthaul technology.

The prediction method using deep learning algorithm has been widely used in PON. Adaptive learning approach DBA [53], to predict the future ONU buffer occupancy using the previous ONU buffer occupancy reports, is recorded in BBU processing. It eliminates the process of reporting ONU buffer occupancy to the OLT and eliminates the DBA process delay. In paper [54], the author proposed a novel DBA based on long short-term memory (LSTM) deep learning method. Recurrent neural network (RNN) introduces a recurrent structure for implementing a memory mechanism to track past information. Through this recurrent structure, the RNN has better performance than the FNN in predicting data with time series. The number of packets that will arrive at the ONU in the next cycle is expected by the LSTM recurrent neural network because of its accurate results the OLT grant bandwidth without waiting for ONU buffer occupancy reposts to the OLT. Some of the TDM-PON-based DBA algorithms for fronthaul technology and its characteristics are tabulated in Table 1.

6 Conclusion

This paper discussed the different solution available for fronthaul technology for CRAN in 5G. It concluded that TDM-PON-based fronthaul is well acknowledged and cost-efficient technology for the CRAN FH network due to inexpensive passive optical components. Using PON infrastructure, the cost of the FH network is estimated at around 60%. The latency issues in conventional TDM-PON are eliminated by using the DBA algorithm. This paper described many DBA algorithms used in TDM-PON-based fronthaul technology and its merit and demerits of traditional DBA and the prediction-based DBA algorithm using deep learning and its advantages.

Table 1 TDM-PON-based DBA algorithm for fronthaul technology and its characteristics

Algorithm	Year of publication	Characteristics
Mobile DBA	2015	Using mobile scheduling information from BBUs for the bandwidth allocation. Need a connection to transfer data from BBU to OLT
Round robin DBA	2014	Uniformly circularly allocates the bandwidth to all T-Conts. Good delay performance. utilization of upstream bandwidth under busty traffic condition is very poor
gGAINT algorithm	2014	Sharing the unutilized data from individual assured bandwidth with other T_Conts of the same group
Optimized RR DBA	2017	Total extra bandwidth from each upstream cycle redistributes to the heavily loaded T-Conts in the next transmission cycle
Adaptive learning approach DBA	2018	Using FANN, predict the future ONU buffer occupancy using the previous ONU buffer occupancy reports recorded in BBU processing
DBA-based on long short-term memory	2019	The number of packets that arrive at the ONU buffer from RRHs is predicted using LSTM RNN because of its accurate results, the OLT grant bandwidth without waiting for ONU buffer occupancy reposts to the OLT

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