5G RAN and Optical Access Coordinated Resource Allocation Framework

[1] Dr Srinivasa Gowda GK, 2 Dr Sunil Jacob
[1]Professsor, [2]Professor
[1]Electronics and Communication Engineering
[1]APS college of Engineering, Bangalore, India

Abstract —the network framework consisting Radio Access Network (RAN) and optical front haul network keeps the resource allocations of wireless-end and optical-end separated from each other with their own QoS requirements. With the increasing demand of diverse applications in future RAN architectures, this traditional resource allocation approach undesirably leads to the resource underutilization and thus restricts the acceptance of demands into the network. To overcome these issues, we propose a new congregated RAN/fronthaul network architecture in which Orthogonal Frequency Division Multiplexing Passive Optical Network (Okl)M-PON) undertakes the role of optical fronthaul for 5G RAN. We consolidate the functionalities of wireless and optical resource allocation such that a Coordinated Optical and WireLess (COWL) resource allocation framework is used to facilitate the globalized End-to-End (E2E) QoS requirements for the converged network. The proposed framework proves to be more scalable to increasing network load and to various resource granularities.

Keywords—RAN, optical fronthaul, coordinated resource allocation, QoS

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing Passive Optical Network (OFDM-PON) emerges as a competitive solution than other PON candidates for the fronthaul of future Radio Access Network (RAN) of 5G and beyond. This is mainly due to its technological superiority in spectrum utilization and large transmission capacity [1][2]. Resource allocation remains as an open issue in OFDM-PON, which refers to the distribution of timeslots and subcarriers among different Optical Network Units (ONUs) based on their bandwidth requests. Related works on resource allocation in converged network of RAN and PON still consider the resource allocation in wireless-end and optical-end separately with their local delay requirements [2]-[5].

A conventional architecture of converged RAN and optical fronthaul network is in Fig. 1, where the wireless OFDM system and OFDM-PON are exploited as RAN and optical fronthaul, respectively. At the wireless-end, the functions of wireless resource allocation are equipped in Baseband Unit (BBU) which schedules the Transmission Windows (TWs) on the basis of demands with their packets queued in User Equipment (UE)/Remote Radio Head (RRH). At the optical-end, the optical resource allocation is implemented in hierarchical mode, in which the Optical Line Terminal (OLT) schedules the TWs for ONI-Js according to their bandwidth requests and then each ONU distributes the granted bandwidth to its demands whose packets are queued in the ONI-J. In such Separated Optical and Wireless (SOW) resource allocation framework it is likely that one domain (optical/wireless) runs out of the bandwidth resource whilst other still has the bandwidth resource unused. The fundamental reason for such unbalanced resource utilization lies in the lack of interaction in the decision-making of resource allocation between wireless-end and optical-end.

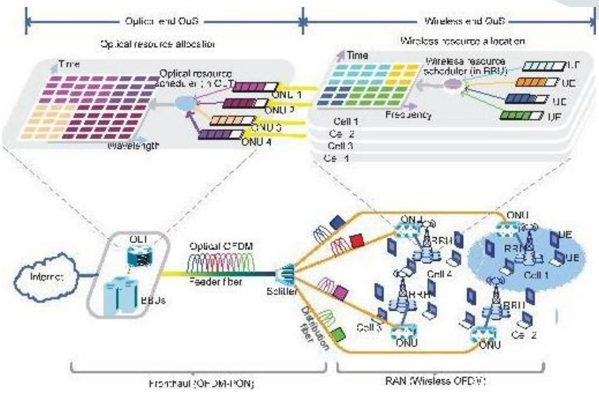


Fig. 1 Separated optical and wireless resource allocation in converged RAN and optical fronthaul network

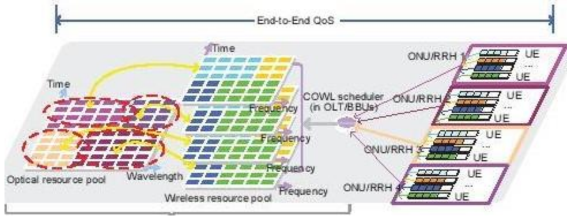


Fig. 2 Coordinated optical and wireless resource allocation in converged RAN,'Fronthaul network

released from the decision-making of resource allocation and act only as executers of COWL scheduler decisions. Each RRH maintains queues to buffer data packets besides the functionality of radio transmitter and receiver. As a result, the local delay requirements at wireless-end and optical-end are replaced with a globalized End-to-End (E2E) delay requirement across both wireless and optical ends. This provides an opportunity to establish an effective coordination between wireless-end and optical-end such that the demand can be accepted as long as the E2E delay requirement is satisfied regardless of the local delay requirement as in the conventional SOW framework.

II. RESOURCE ALLOCATION IN CONVERGED RAN/FRONT HAUL NETWORK ARCHITECI'URE

As expected in 5G network, the E2E delay from I-JES to OLT/BBUs is chosen as a typical metric to measure the QoS of demands. Each I-JE can raise a demand of a particular service type with the specified E2E delay requirement. The demand will be accepted only if its QoS requirement (i.e., E2E delay) can be satisfied with enough wireless and optical resource and rejected otherwise. The actual delay performance of each demand depends on the bandwidth resource that are allocated at wireless-end and optical-end, which is ultimately dependent on the sizes of wireless and optical TWs their locations in the resource pools.

Aiming to maximize the acceptance ratio of demands, we focus on how to allocate the wireless resource and optical resource under the constraints of OFDM-PON and wireless OFDM system. This includes three major constraints:

i) End-to End Delay Requirement

The E2E delay comprises transmission delays, propagation delays, and queuing delays at both wireless-end and opticalend. A demand can be accepted only if its E2E delay is less than or equal to the required value.

il) Time/Frequency Continuity of transmission Window

In order to reduce the overhead and operational complexity, both wireless and optical TWs that are allocated to each demand, as well as to each ONU/RRH, should ensure the time/frequency continuity [3]. Therefore, as shown in Fig. 2, each TW in wireless resource pool and optical resource pool appears to be a rectangular zone of Resource Units (RUs) within continuous frequency and time range. iii) Contention-Free Resource Allocation for the sake of contention-free transmission, each wireless RU of any cell/RRH can be occupied by at most one demand in this cell/RRH. However, the wireless RU can be shared among the demands in different cells that are far away enough to keep free of interference from each other. In optical resource pool, each RU can be occupied by at most one demand regardless of cells.

III. HEURISTIC FOR TW PLACEMENT

The E2E delay is mainly dependent on locations and sizes of TWs. With the E2E delay requirement, the problem of TW placement can be translated to find an appropriate location and size for each TW in each frame of the wireless and optical resource pool. However, not all demands can find the appropriate TWs in the wireless or optical resource pools due to the existence of resource fragmentation.

We observe that the fragmentation appears more often when the TWs are placed inegularly. We are motivated by this observation to allocate the wireless and optical resource according to a from-bottom-to-top principle, in which the wavelength/frequency and time are used as the horizontal axis and vatical axis of the resource pools, respectively. We place each TW from bottom to top in both wireless and optical resource pools.

We refer to the zone in the resource pool of one frame that has been filled with TWs as TW heap, which represents the status of the occupied resource in that frame. However, there is an implication of the TW heap's boundary on the resource fragmentation. The resource fragmentation would appear more often if the boundaw of the TW heap fluctuates frequently and intensively. It is evident that an advisable TW placement solution should target at mitigating the fluctuations of TW heap. Besides the TW placement for each demand, we need to consider the TW placement for each ONU/RRH, which makes the TW placement in optical resource pool less flexible than that in wireless resource pool. We propose a hierarchical TW placement algorithm in which the TW placement for ONI-Js/RRHs precedes the TW placement for demands. The procedure of TW placement is depicted in Algorithm

Algorithm 1: Heuristic algorithm for TW placement

Input: Packet arrival rate and E2E delay requirement for each demand; Output: Start subcarriers, end subcarriers, start timeslots and end timeslots of the optical TW and wireless TW;

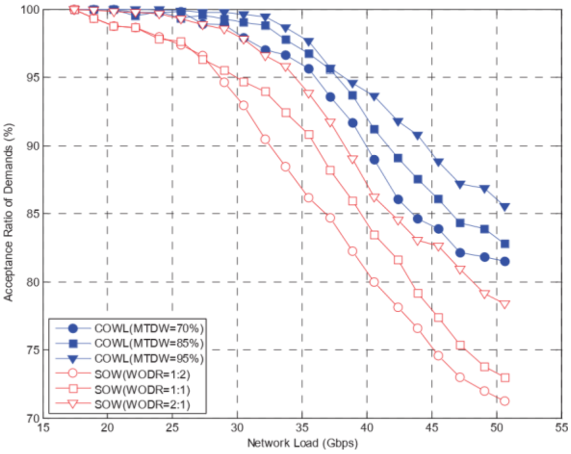
I : Sort all ONUs,RRHs according to decreasing optical resource requests;
2: ror each ONU/RRH do
3: Sort the demands according to decreasing optical resource requests;
4: for each demand do
5: Select the optical resource stack and determine the initial location of optical TW•,
6: Select the wireless resource stack and determine the initial location ofwireless TW;
7: Calculate E2E delay according to the initial TWs;
8: while E2E delay requirement is not satisfied do
9: Reshape the wireless and optical TWs;
10: end while ifE2E delay requirement
11: is not yet satisfied then
12: Reject the demand;
13 else Accept the demand and record the TWs;
14: end if
15: end for

TABLE I SERVICE SETTING

Service Typ e	E2E Delay Requirement (ms)	Packet Arrival Rate (Packets/s)	Packet Length (Bytes)
Service A	2ms	8000	
Service B	5 ms	6000	1500
Service C	10ms	5000	1000
Service D	20ms	3000	500

IV. PERFORMANCE EVALUATION

For the performance evaluation of the coordinated framework, we plan a network area with 8 cells, each of which has an ONU/RRH at the center. In each cell, we distribute a random number of UEs. We set four types of services, A, B, C and D as shown in Table I. Each cycle has the length of 50ms, divided into 10 frames. In each frame, the numbers of wireless timeslots, optical timeslots, wireless subcarriers, optical subcarriers are set to 100, 200, 128, and 256, respectively.



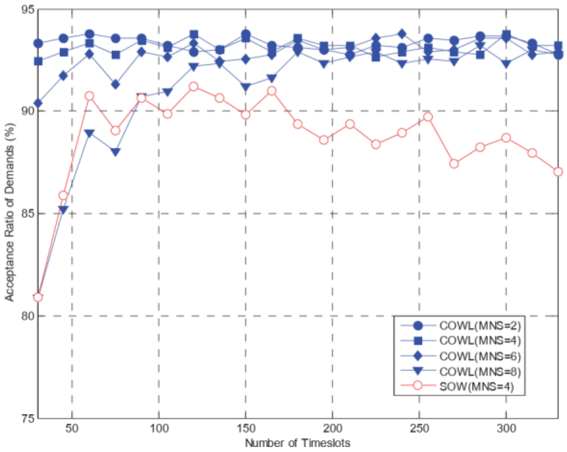


Fig. 3Acceptance ratio of demands with different network loads Fig. 4 Acceptance ratio of demands with different number of timeslots

In Fig. 3, we evaluate the acceptance ratio of demands with the network load increasing from 17Gbps to 50Gbps. We introduce the maximum tolerable delay into the wireless-end and the optical-end to mitigate the prohibitively unbalanced resource allocation. In order to analyze the impact of different delay requirements, we generate three COWL paradigms by setting the Maximum Tolerable Delay Weight (MTDW) to 70%, 85% and 95%, and three SOW paradigms by setting the Wireless to Optical Delay Ratio (WODR) to 1:2, and respectively. Both of COWL and SOW undergo a declining acceptance ratio of demands with the network load increasing. We define the network congestion as a state in which the acceptance ratio drops below 98% The network begins to go into the congestion state with plat of the wireless or optical resource unoccupied whether it is operated within SOW or COWL. This is due to the resource fragmentation arising from the time/frequency continuity constraint on TW placement. However, we observe that the network under the operation of SOW (WODR=2:1) enters congestion when the network load gets above 30.5 Gbps, while COWL is capable to undertake the network load up to 35.5 Gbps free of network congestion (i.e., 0.62 Gbps higher than SOW per cell). In order to evaluate the impact of resource granularity, we show the results of acceptance ratio generated with the increasing number of timeslots in Fig. 4. The Maximum Number of Subcarriers (MNS) for each demand is also adopted as a parameter of interest to generate different COWL paradigms. The MNS value acts as a direct constraint on the horizontal width of wireless and optical resource stacks for TW placement. It is clear from the results that the acceptance ratio performed by SOW features an intensive fluctuation, which results from the irregular change in the portion of surplus resource in TWs. Due to the flexibility in resource allocation and the capability in reducing surplus resource, ow COWL framework proves to be less susceptible to the varying resource granularity with a relatively steady acceptance ratio.

CONCLUSION

We aimed to address the issue of resource underutilization inherent in the separated resource allocation framework of converged 5G-RAN and optical fronthaul network. We proposed a converged 5G-RAN/fronthaul network architecture in which OFDM-PON is exploited as fronthaul and the functionalities of OLT and BBUs are integrated to support the Coordinated Optical and WireLess (COWL) resource allocation. The results showed that the proposed COWL framework is capable of guaranteeing the latency requirement of next-generation application and more resilient to higher network loads and changing resource granularities.

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