Mobile Xhaul Traffic Modelling for High-Speed TDM-PON

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Abstract We provide an analysis of mobile transport capacity requirements for 5G cellular networks based on system level radio simulations. We propose high-speed TDM-PON as transport technology for small cells and validate efficient aggregation in the C-RAN architecture, especially when aggregating latency-sensitive and latency-tolerant transport.

Introduction

As 5G technologies get standardized and mature beyond the initial proof-of concepts and field trials, network operators need cost-efficient solutions for large scale commercial deployments. Centralized Radio Access Network (C-RAN) as a generic architecture, offers significant benefits by pooling of resources. The C-RAN architecture in 5G is envisioned to be realized as virtual functions in the cloud with open interfaces that require a transport network between the radio processing functions with certain capacity and latency requirements. Various mobile standards development organizations have proposed different functional-split options for the RAN that enable the benefits of centralized processing with significantly lower transport bandwidth requirements compared to previous generation C-RAN interfaces (e.g. CPRI) [1]. Fig.1 shows an example of functional-split processing option where the 5G RAN protocol stack as described in [2] is grouped into three RAN entities of Radio Unit (RU), Distributed Unit (DU), Central Unit (CU). The functional split between the CU and the DU is the High-Layer Split (HLS). The data between them can be carried over so-called midhaul links, employing F1 interface specifications. The functional split between the DU and the RU is the Low-Layer Split (LLS) which can be implemented in different ways [3-4] some of which are shown in Fig. 1. The data between the DU and the RU can be carried over fronthaul links, employing LLS interface specifications [4]. In this paper, we use the terminology xhaul when referring to these interfaces together. The High-Layer and Low-Layer splits are designed in such a way that the transport traffic between the RAN entities is dependent on the user data traffic and on the radio channel conditions, therefore, enabling the use of statistical multiplexing transport technologies such as Packet Transport Network (PTN). Unlike point-to-point or Wavelength Division Multiplexing (WDM) technologies, PTN employs packet multiplexing methods to share multiple connections over the same network. TDM-PON is one such widely used fibre access technology that provides a cost-efficient solution for a point-to-multipoint aggregation network architecture. And depending on the split ratio (e.g. 1:32 or 1:64), it allows for very high-density deployments (e.g. FTTH) which can be leveraged by operators to densify their cellular networks. Existing commercial TDM-PON technology can provide up to 10 Gbps symmetric bitrate as per XGS-PON standard. The next generations of TDM-PON, under definition at IEEE and ITU, will provide 25 and 50 Gbps bitrate that can cost-effectively serve 5G xhaul traffic.

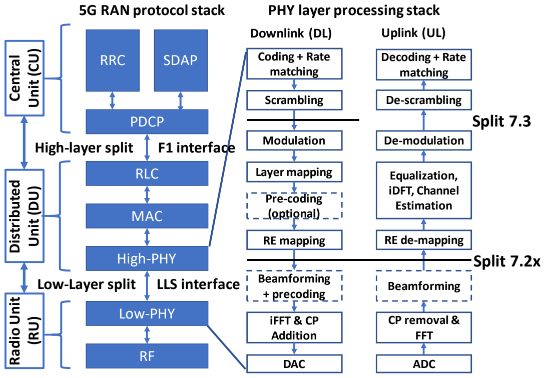

Fig. 1: 5G RAN split-processing architecture example

For specifying optimal TDM-PON solutions for xhaul architectures, the radio traffic characteristics need to be well understood. In combination with the dynamic bandwidth assignment features in TDM-PON, they will allow for designing cost optimized x-haul networks. The NGMN Alliance has published dimensioning guidelines for the aggregated backhaul capacity in LTE networks based on the results of a numerical analysis, assuming statistical traffic of user data [5]. In a more recent study, the authors of [6] considered pre-standard 5G scenarios and provided the transport capacity requirements for different split-processing options based on the guidelines in [5]. The results in [6] are based on the extrapolation of 15 min average measurement data from a live LTE network to 5G services of the same type, but at higher capacity. However, considering 15 min time span averages is not sufficient for modelling the dynamic traffic statistics to be transported over a TDM-PON system which works with a frame transmission every 125 µs and with ms-scale adaptation of dynamic bandwidth allocation.

Therefore, in this paper, we perform for the first time a detailed xhaul traffic analysis using system level radio simulations as specified by 3GPP [7]. We use fine granular time-series data generated for every radio slot of 0.5 ms to get a better understanding of the statistical traffic requirements for xhaul. In the following sections, we describe the system level radio simulation methodology and parameters. The results of our xhaul traffic calculations are followed by an analysis of the number of xhaul connections that can be aggregated using a high-speed TDM-PON.

Setup of the system level radio simulations

3GPP has described reference scenarios in order to perform system level radio simulations for different cellular network deployments [7-8]. The Urban Macro Cell (UMa) scenario from [7] with 3D channel model is used for our simulations. However, it is adapted to the 5G numerology, modulation and coding scheme (MCS) tables and other main parameters as mentioned in Table 1.

	Urban Macro Cell (UMa)
Layout	Hexagonal grid, 19 cell-sites, 3 cells (sectors) per site.
Inter-Site Distance	500 m
Antenna Height	25 m
Carrier Frequency	3.5 GHz
Duplexing mode	Freq. Division Duplex (FDD)
Spatial MIMO Layers	4 x 4 (Single User - MIMO)
Carrier Bandwidth	100 MHz
Subcarrier Spacing	30 kHz
RU Tx power	56 dBm
Radio Scheduler	Proportional Fair
Number of User Elements (UEs)	1,5,10,20,30,40 UEs/cell * 57 cells
UE distribution	Uniform in the network
UE traffic profile	FTP 3 (File Transfer Protocol): File size: 0.1, 0.2, 0.4, 0.5, 1.0, 2.0, 4.0 Mbytes Avg. request rate: 0.1, 0.2, 0.5, 1.0, 2.0, 2.5, 4.0 req./sec

Table 1: Radio system level simulation parameters

The simulation program generates the enhanced Mobile Broadband (eMBB) type of data traffic per user based on the FTP3 traffic model [8] which generates a Poisson process of random requests using an average request rate with constant file size for each request, both listed in Table 1. The radio scheduler uses a proportional fair scheduling algorithm while considering the radio channel conditions and corresponding link adaptation techniques to achieve a certain Block Error Rate (BLER) target (e.g. 10% in the case of eMBB services). The output of the simulation is the time-series of UE scheduling information in the downlink direction for each radio slot of 0.5 ms. The UE scheduling information is then used to calculate xhaul traffic demand for each cell per radio slot at the F1 (HLS) interface, split 7.3 and split 7.2x LLS interface. To generate a certain requested traffic load for a single cell, we consider multiple combinations of user density and traffic volume per user (described by [#UEs per cell, file size, average request rate] tuple).

Xhaul Traffic Requirements

The theoretically calculated peak traffic requirements assuming perfect channel conditions for a single cell of the configuration in Table 1 at the F1, LLS (Split 7.3) and LLS (Split 7.2x) interface are approximately 1.94 Gbps, 2.1 Gbps and 6.73 Gbps respectively. The peak traffic requirements scale linearly with carrier bandwidth and MIMO layers. However, due to the radio channel conditions and the user traffic requests in the simulated multi-cell environment, the theoretical peak is rarely achieved. In this xhaul traffic analysis, following from [5-6], 95%ile values are used from the distribution of the sum of F1 traffic requirements of a certain number of cells per radio slot, whereas maximum (i.e. 100%ile) values are used for LLS traffic requirements. As F1 interface traffic is latency-tolerant for eMBB services, the instantaneous traffic exceeding the provisioned capacity will not necessarily lead to packet loss due to the ability of delayed retransmission. However, as LLS traffic is latency sensitive, we need to provision for the maximum requirement. Since we want to calculate the mean xhaul traffic requirements for the aggregation of multiple cells, the traffic requirements from multiple randomly combined cells of a given group size is averaged (e.g. taking the mean of 50 random combinations of 10 cells from our 57-cell scenario). The xhaul traffic requirements are evaluated for different user data traffic loads for each cell using a combination of user density and requested user data traffic volume. The load percentages are given with respect to the theoretical peak capacity of a single cell at the F1 interface which is almost equivalent to the air interface capacity of the cell.

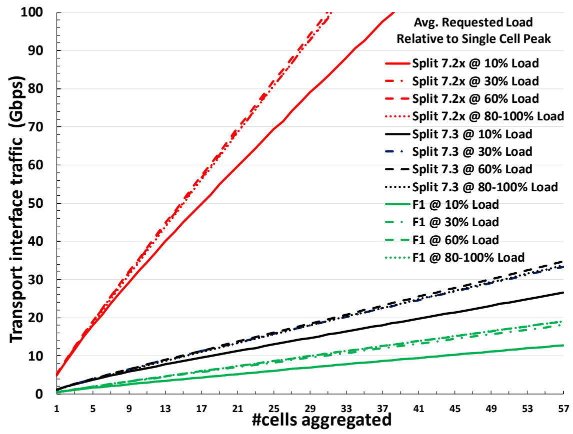

Fig.2: Traffic requirements for F1 and LLS interface

Fig. 2 shows xhaul traffic requirements as a function of the number of aggregated cells (cell=sector for multi-sector cell-sites). It can be observed that for a given number of aggregated cells, the F1 traffic requirement increases with requested load up to 60%. This is because at (or close to) 60% requested load, the overall capacity of the radio network is reached based on the interference limited channel conditions of the simulation scenario and hence no more data can be served from the cellular network even when the requested load is increased to 80-100%. The F1 traffic requirement increases linearly for a given requested load as the number of aggregated cells increases. This is due to similar channel conditions and user traffic requirements for each cell due to the homogeneous cellular network simulation scenario. The 7.3 fronthaul split option carries the Forward Error Correction (FEC) coded F1 interface data and hence has a slightly higher traffic requirement compared to the F1 interface. Based on our simulation results in Fig. 2, the 7.3 fronthaul split option traffic is ~1.5 times the F1 traffic – meaning the FEC coding step added ~ 50% redundancy on average. It is also seen in Fig. 2 that the traffic requirements at 7.2x split option are much higher compared to the 7.3 split option. This is because the 7.2x split option carries the modulated frequency domain In-phase and Quadrature (IQ) data with a fixed number of bits used for each radio Resource Element (RE) (i.e. 1 symbol and 1 subcarrier). The information bits at the 7.3 split interface get converted to a higher bit IQ representation (e.g. 9 bits each for I & Q used in our calculations) irrespective of the modulation level. The difference between the 7.3 split data and 7.2x split data increases in the case of lower modulation level e.g. Quadrature Phase Shift Keying (QPSK) modulation has only 2 information bits per radio RE at 7.3 split option which are converted into 18 bits of IQ data to be carried over the 7.2x split LLS interface resulting in almost 9 times increase in 7.2x interface traffic compared to 7.3 split.

Xhaul over TDM-PON

Even though the traffic scales linearly with the number of aggregated cells due to homogeneity of the simulation scenario, there is temporal randomness within the xhaul traffic at every cell. The temporal randomness in the xhaul traffic can be exploited efficiently in the TDM-PON which can adapt its dynamic bandwidth allocation at ms scales. Considering the overall traffic capacity requirements and the temporal randomness in the traffic at each cell, a high-speed TDM-PON can be efficiently used to aggregate multiple radio cells. Since a typical PON serving area spans ~ 1 km^2, it can cover a reasonable #cells depending on the inter-cell distances. In this section, we analyse the number of xhaul connections from our simulation scenario, that can be aggregated on a single TDM-PON. We consider a 25G TDM-PON as an example with the effective downstream throughput of 20.5 Gbps considering Forward Error Correction (FEC) and other protocol overheads of TDM-PON. In a radio deployment where all cells in our simulation scenario have the same type of xhaul interface, 25G TDM-PON can support up to 5 cells with LLS (7.2x split), 33 cells with LLS (7.3 split) and 57 cells with F1 interface. We also consider a mixed radio deployment where some cells with an F1 interface and some with an LLS interface are within the same PON serving area. Since LLS interface is latency-sensitive (up to few 100 µs), and F1 interface is latency-tolerant (up to few ms for eMBB), aggregation of cells with different xhaul interfaces on the same TDM-PON can connect higher #cells while also satisfying their latency constraints.

The graph in Fig. 3, shows the maximum number of F1 interface cells and LLS interface cells that can be aggregated on a 25G TDM-PON for a certain load condition and LLS split option. The points under the line graph depict all feasible combinations of aggregated cells with LLS and F1 interface. It can be observed in Fig. 3 that even in high load cases, upto 4 cells with LLS (7.2x split) interface and upto 14 cells with F1 interface can be supported on a 25G TDM-PON. Similarly, for high load cases, up to 15 cells with LLS (7.3 split) interface and up to 24 cells with F1 interface can be supported. The xhaul network dimensioning with a mixture of cells with F1 and LLS interface leads to a higher aggregation of number of cells on the TDM-PON.

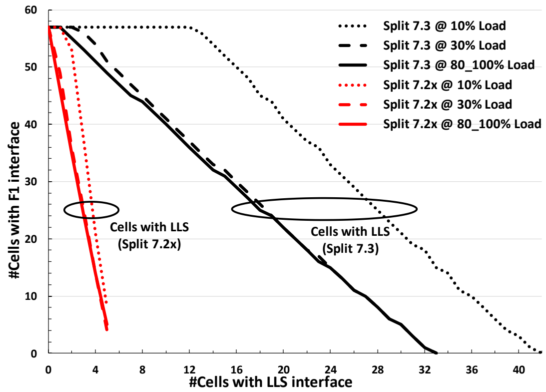

Fig. 3: F1 and LLS aggregation on a 25G TDM-PON

Conclusions

In this paper, we presented 5G xhaul transport requirements for the C-RAN architecture based on detailed system level radio simulations. The resulting traffic requirements show that high-speed TDM-PON is a good option for 5G xhaul transport of small cells with F1 or LLS (7.3 split) interface and is even better when combining F1 and LLS (7.2x split or 7.3 split) interface traffic on the same transport network.

Acknowledgements

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