Dynamic Transport for 5G Traffic in Dense Areas

V. Eramo(*), M. Listanti(*), F.G. Lavacca(*), P. Iovanna(**), G. Bottari(**), F. Ponzini(**)
(*)DIET, Sapienza Universita' di Roma, 00184 Roma, Italy, (**)Ericsson Research, Via Moruzzi 1, 56124 Pisa, Italy
{Vincenzo.Eramo,Marco.Listanti,Francesco.Lavacca}@uniroma1.it; {paola.iovanna, giulio.bottari, filippo.ponzini}@ ericsson.com

Abstract: A novel dimensioning and operational procedure is presented and assessed by simulations to face Tbps/km^2 traffic expected in 5G. Broadband access in dense areas is modeled in traffic and transport to take into account the dynamic traffic behavior in time and space.
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1. Introduction

Based on different studies and predictions [1], it is possible to conclude that beyond 2020, mobile networks will be asked to support more than 1,000 times today's traffic volume. Demands for greater mobile networks capacity and for increased data rates are just two of the requirements posed in the evolution of radio access networks. Other fundamental factors are energy consumption cost of systems, latency, spectrum availability and spectral efficiency.

Mobile networks are today designed for continuous and highly reliable operation, which traditionally has been associated with an "always on" operation, implying that nodes and components are always active to be immediately available where and when needed. Hence, the energy consumption in current radio networks is not very dependent on traffic load. For deployment of 5G, there are stronger and more clearly defined requirements on high energy performance than before. Operators explicitly mention a reduction of total network energy consumption by 50 % despite the expected 1,000-fold traffic increase. These results can be achieved only by temporary deactivating network resources, like small cells, when the traffic is reduced.

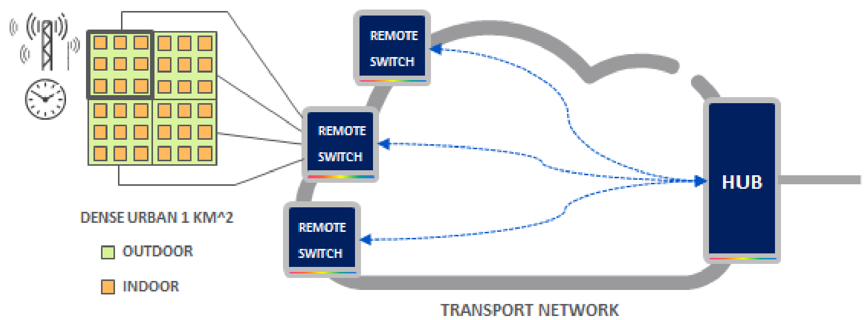

Fig. 1 – Reference Architecture

Another important aspect is related to the optimization of the transport network which acts as backhaul and/or fronthaul for the radio traffic. With traffic expectation in the order of magnitude of several Tbps/km^2, a radical optimization of the transport network is unavoidable. It means rethinking the network architecture and its control.
An emerging network paradigm, labeled as "Xhaul", wraps fronthaul and backhaul in a common connectivity segment providing a joint optimization opportunity, especially in sharing transport resources for different purposes and protocols. Xhaul unifies and enhances the traditional backhaul and fronthaul areas by enabling a flexible deployment and reconfiguration of network elements and networking functions. It also facilitates the baseband processing centralization, achieved by pools of digital units. The role of the Xhaul transport network is to convey Ethernet traffic and CPRI traffic on the same network infrastructure. A relevant case is the use of a WDM optical network to transport Ethernet and CPRI over optical channels possibly sharing the same channel for heterogeneous traffic. Transport of future protocols will be similarly possible on Xhaul, for example in support of alternative splitting strategies in the radio layer.

Of the several use cases predicted for 5G, this study addresses the "broadband access in a dense area" scenario (Fig.1) characterized by an outdoor area (streets, squares) and by an indoor area (buildings) with traffic density as critical parameter. A *reference area* of 1 km^2 is assumed. A model for radio traffic variations is proposed, bounded to the maximum peak values indicated in [1]. The radio network is arranged as a set of Remote Radio Units (RRU), serving macro cells and small cells, transmitting CPRI flows across the Xhaul transport segment towards the core. Part of the RRUs is activated/de-activated to follow the radio traffic demand. A dimensioning procedure is illustrated allowing a significantly lower number of CPRI flows with respect to the case in which the number of CPRI flows is statically fixed to the number of installed RRUs. This study aims at quantifying the potential advantages in terms of bandwidth obtainable via: i) an activation/deactivation policy of RRUs associated to the small cells and ii) a full sharing of transport capacity in the Xhaul". The development of an analytical model quantifies the advantages.

2. Network and Traffic Models

According to the broadband access in dense urban model [1], 188 buildings are present in the reference area, each building having a floor surface of 1600 m^2. The indoor area is 188 * 1600 = 300,800 m^2, it means ≅ 30% of the reference area. The remaining 70 % is assumed as outdoor. According to 5G traffic forecasts, the traffic densities in the Peak Hour Interval (PHI) in the indoor and outdoor regions are assumed to be 15000 Gbps/Km^2 and 750 Gbps/Km^2 respectively. Said traffic is assumed to be cycle-stationary, wherein: Q is the cycle-stationary period, ΔQ is the stationary interval, and $N=Q/\Delta Q$ is the number of stationary intervals in the period of duration Q. We consider stationary intervals of duration ΔQ=1h with both daily (Q=24h, N=24) and weekly (Q=168h, N=168) traffic profiles.

The average peak traffic in the stationary intervals are evaluated according to the previously mentioned traffic densities, the considered area and the daily and weekly traffic profiles of the City of London normalized to the traffic in the PHI [2]. Peak traffic distribution is assumed to be lognormal [3] in each time interval k (k=0,..,N-1) with parameters μ^k and σ^k that are chosen so as to guarantee for the distribution both the forecasted average peak traffic and a typical standard deviation equal to 0.25 [3].

The reference area is assumed covered by a set of macro cells providing the basic radio coverage. Inter-site distance between contiguous macro cells is ISD = 200 m, resulting in 25 macro cells in the area. Each macro cell is then complemented by a number T of sub-areas providing a capacity increase when needed. The macro cell has three sectors, each sector served by one CPRI flow. Each sub-area is composed by small cells that, instead, are equivalent to a single sector and are served by a single CPRI flow.

As said, macro cells provide the basic radio coverage. Associated RRUs and the relevant CPRI flows are considered always on. Small cells can be active or not and the expected resource savings come from the opportunities to deactivate RRUs and relevant CPRI flows. This evaluation is done every hour. The adopted technique consists in switching on the least number of RRU so as to have sufficient capacity guaranteeing the α percentile (α-th) percentile of the peak traffic in each time interval.

3. Dimensioning of the number of RRUs and CPRI flows

The objective is to evaluate the saving of CPRI flows that a reconfigurable (optical) network [4] allows when strategies for the RRU switching on/off are applied.

The saving will be evaluated when a Remote Switch (RS) is considered handling the traffic generated between S macro-cells and a Centralized Hub (CH). We assume that each macro-cell is composed by T sub-areas. To carry out the evaluation we introduce two analytical models. The first one allows for the dimensioning of the number n_{RRU} of RRUs to be installed in each sub-area. The second one allows for the evaluation of the number $n_{CPRI,k}$ of CPRI flows in each time interval k (k=0,1,…,N-1) to be supported between the RS and the CH. The percentage gain in the time interval k of the proposed solution is expressed by $g_k=100*(1- n_{CPRI,k}/STn_{RRU})$.

The number n_{RRU} of RRUs is evaluated so as to guarantee that the provided capacity satisfies the α-th of the peak traffic generated in the PHI, whose index is denoted with k_{PHI}. If we denote with C_{RRU} the capacity of any RRU and we assume that the Macro Base Station (MBS) capacity C_{MBS} is equally distributed among the T sub-areas, the dimensioning of RRUs is accomplished by choosing the smallest integer number n_{RRU} such that the following expression holds:

$$\frac{1}{2} erfc\left(-\frac{\ln\left(n_{RRU} C_{RRU} + C_{MBS}/T - \mu^{k_{PHY}} \right)}{\sigma^{k_{PHY}} \sqrt{2}} \right) \geq 0.01\alpha \qquad (1)$$

To evaluate the values $n_{CPRI,k}$ (k=0,1,…,N-1) of CPRI flows, we assume statistical independence of the traffic generated in each sub-area and we start by the knowledge of the statistical on the number $N_{RS,k}$ (k=0,1,…,N-1) denoting the sum of switched on RRUs and MBS sectors of the S macro-cells handled by the RS. We choose $n_{CPRI,k}$ as the α-th of $N_{RS,k}$ that is the smallest value for which the expression $\Pr\left(N_{RS,k} > n_{CPRI,k}\right) < 1 - 0.01\alpha$ (k=0,1,…,N-1) holds. Due to the statistical independence of the number of switched on RRUs and MBS sectors for the S macro cells, we can evaluate, by a simple convolution operation, the statistical of $N_{RS,k}$ from the one of the number $N_{MC,k}$ of switched on RRUs and MBS sectors in each macro-cell. For the evaluation of the $N_{MC,k}$'s probabilities we take into account that: i) one MBS is always switched on and it is composed by three sectors; ii) a switched off algorithm is applied in the macro cell so as to switch on the least number of RRUs that handles the α-th of the peak traffic generated in the macro cell in the traffic interval k; iii) it is proved that this traffic can be approximated with a lognormal distribution of parameters μ_{MC}^k and σ_{MC}^k that are tied to μ^k *and* σ^k [5]. According to this observations we can express the $N_{MC,k}$'s probabilities as follows:

$$
\Pr\{N_{MC,k}=i\}=\begin{cases}
0 & i\in[0..2] \\
\frac{1}{2}erfc\left(-\frac{\ln C_{MBS}-\mu_{MC}^{k}}{\sigma_{MC}^{k}\sqrt{2}}\right) & i=3 \\
\frac{1}{2}erfc\left(-\frac{\ln\left(C_{MBS}+(i-4)C_{RRU}\right)-\mu_{MC}^{k}}{\sigma_{MC}^{k}\sqrt{2}}\right)-\frac{1}{2}erfc\left(-\frac{\ln\left(C_{MBS}+(i-3)C_{RRU}\right)-\mu_{MC}^{k}}{\sigma_{MC}^{k}\sqrt{2}}\right) & i\in[4..Tn_{RRU}-1] \\
1-\frac{1}{2}erfc\left(-\frac{\ln\left(C_{MBS}+Tn_{RRU}C_{RRU}\right)-\mu_{MC}^{k}}{\sigma_{MC}^{k}\sqrt{2}}\right) & i=Tn_{RRU}
\end{cases} \tag{2}
$$

4. Numerical Results

In this section, we report some dimensioning results in the case of a RS handling the traffic of S=5 macro areas each one composed by T=9 sub-areas. In our analysis, in order to deal the high forecasted traffic demand, we consider MBS transceivers with an LTE BW equal to 20 MHz and MIMO 8x8 for each sector that are characterized by a capacity C_{MBS}=1.8 Gbps. RRUs with the same hardware characteristic of a MBS transceiver are considered and characterized by a capacity of C_{RRU}=600 Mbps. Each MBS and RRU generates 3 and 1 CPRI flows (10 Gbps) respectively. The number n_{RRU} of RRUs installed in each sub-area and the number $n_{CPRI,k}$ ($k=0,..,N-1$) of CPRI flows are evaluated by applying the procedure defined in the previous section by considering α= 99,99.

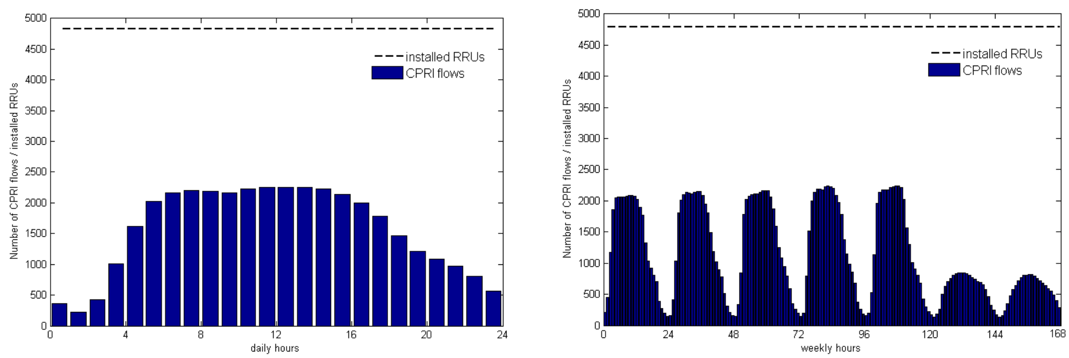

Fig. 2 - Dimensioning values $n_{CPRI,k}$ as a function of the hour in the cases of daily (left) and weekly (right) traffic profiles.

In Fig. 2, the dimensioning values $n_{CPRI,k}$ of CPRI flows are reported for daily and weekly variations. With respect to the case in which the number of CPRI flows is equal to the number of installed RRUs (dotted horizontal line) that is equal to 4815, the number $n_{CPRI,k}$ of CPRI flows to be supported between the RS and the CH evaluated by our analytical models is lower, leading to significant values for the percentage gain g_k . During the PHI, the number $n_{CPRI,kPHI}$ of CPRI flows is 2252, leading to a percentage gain g_k equal to 53,2%. Higher gains can be achieved in the other traffic intervals when traffic reduction occurs and the switching off technique is applied. In these cases the saving can also reach the 95%.

The CPRI circuits saving is achieved by the combination of two optimization strategies: i) the application of an algorithm of RRU switching off applied when the offered traffic decreases; ii) the statistical multiplexing advantages that leads to a less severe dimensioning, even during the PHI, due to the fact that the first aggregation node (RS) has to provide CPRI circuits for an aggregate of sub-areas while the number of RRUs installed is dimensioned according to the traffic amount offered to every single sub-area.

5. Acknowledgment

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6. References

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