**Title :** Architecture for routing and scheduling algorithms to guarantee low latency and no jitter in 5G and beyond systems

Current mobile network (aka cellular network) architecture consists in a distributed radio access networks: the mobile terminals connects to base stations (BTS for Base Transceiver Station as a generic name, eNB for evolved Node B in 3GPP LTE “4G” standard) that encompasses all the sub-systems needed to realize mobile communication [Ref]. It mainly comprises the radio part, that furnishes the connection between the mobile terminal and the BTS, and the network part that provides control and management functions like mobility support (the main functionality being the support of handover from one BTS to another, i.e. the ability to pursue a communication when moving from range of an antenna to another.) The evolutions proposed in next generations aim at evolving toward centralized radio network architectures (C-RAN, for Cloud Radio Access Network) to reduce consumption costs and power at the base stations [Ref]. These C-RAN architectures include simplified base stations on the field. Depending on the architecture choice, it can be restricted to the radio part and the digital to analog conversion only. This can be identified by different names depending on the reference documents, including RU for Remote Unit or Remote Radio Heads (RRH). The later will be used the rest of the document. The other component of the C-RAN is composed of the processing units (baseband unit: BBU – used in this document – or FU for Frontend Unit) located in the cloud. By cloud we define in this document the capability of instantiating executable programs in data center that are transparently connected to the systems that require the results of the program execution [Ref]. The execution may be indifferently performed on virtualized machines, or bare metal one, or any other combinations. The network between RRH and BBU is called “Fronthaul Network”, or Fronthaul for short.

Thus this type of architecture faces to the problem of mastering the latency in the transfer process between on the field RRHs and BBUs in the cloud.

Low latency is already critical for the deployment of C-RAN approach in LTE “4G” networks. The standard requires meeting time constraints for functions like HARQ (Hybrid Automatic Repeat reQuest) that needs to be processed in less than 3ms [Ref]. Considering processing time into the BBU, the time budget over the network can be as low as 400 micro seconds for round trip time. One specificity in this C-RAN context is not only the latency constraint, but also the periodicity of the data transfer between RRH and BBU (this HARQ constraints must be enforced for each frame emitted every millisecond.) New scheduling and routing paradigms and new technologies have to be considered to guarantee delay constrained periodic data transfers. Dynamical optical bypass and dynamical management of the emission should be considered to guarantee latency constraints [Ref].

Looking beyond current mobile network generation, one must have in mind that ongoing 5G standards require to reach end-to-end expected latency from 1 to 10ms (depending on targeted services) [Ref].

The expressed constraints expressed for C-RAN architecture and 5G standard are hardly met in the up to date networks. In IP or even Ethernet networks, the traffic usually suffers of delay due to buffering. The amazing success of the packet based networks for the last 40 years relies on the statistical multiplexing: the packets are sent when they are ready and are buffered in intermediate nodes (routers for IP networks, switch for Ethernet networks) when contention arises [Ref]. A contention means that one resource (node out interface) is needed at the same time for transmission of several packets. In this case, the supplementary packets are stored in a buffer until the resources become available. This allows an easy deployment and management of a network, leading to a delivery of the packet with few loss (under conditions that buffers are big enough) but at the price of uncertainty on the delivery time. This uncontrolled and non predictable delay prevents to offer low latency and no jitter in the current network. Best Quality of Service (QoS) solutions do not allow contention avoidance or management, then they can not provide controlled low latency [Ref]. If they can be used to prioritize some packets over the others (e.g. Express Forwarding against Best Effort), they fail to ensure delivery of packets in a given time delay when several priority packets compete for the same resource.

The best current solution is to rely on an almost full optical approach, where each end-points (RRH on one side, BBU on the other side) are connected through direct fiber or full optical switches [Ref]. This architecture is very expensive and hardly scales in the case of a mobile network. As illustrative purpose, a single (one operator) mobile network in France is composed of about 10,000 base stations. This number will increase by a factor of 2 to 20 with the emergence of “small cells” that allow increasing base station density and to reach higher throughput [Ref]. It is then needed to find a solution to offer low latency over communized packet based networks.

Thus, this PHD subject targets to elaborate an architecture for low latency packet network including new scheduling and routing paradigms to solve this periodic and delay constrained data transfer. Indeed, one of the most promising approaches relies to their the concept of Deterministic Networking (DN) such that one getgets rid of statistical multiplexing. The traditional queue managements are replaced by time based forwarding. Solutions for Deterministic Networking are under standardization in IEEE 802.1 TSN group [Ref], as well at IETF DetNet working group [Ref]. To make DN working over a network composed of several nodes, it is needed to manage the time at which the packets of deterministic paths are crossing each nodes [Ref].

A first algorithmic modelisation have been proposed and analyzed in collaboration between Nokia Bell Labs France and DAVID laboratory. Considering a graph modeling the network topology, and a set of routes from source nodes (modeling connections to data-centers) and destination nodes (modeling base stations) in this graph, the purpose is to select, for each destination node a route from one source node to it and a periodic routing scheme allowing to periodically send a packet to each base station without congestion conflicts between all such packets, to insure a minimum latency. Given maximum values of the data transfer time (about 3 ms included the computation time in the cloud in the C-RAN context) and of the periodicity (about 1 ms in the same context), in a slotted time model, the aim is here to minimize the duration of the period, with a constraint of the maximum length of routes to be selected. Even if the selected set of routes is given this optimization problem has been shown to be NP-complete [Ref]. We plan to study several topologies of networks: the star for which several results are already available, the cycle representing an optical ring and the acyclic graph representing a general meshed network. We will try to characterize the restrictions of the previous topologies which make our problem polynomial time solvable or approximable. In particular, the time to transmit a packet seems to be large with regards to the size of a route. We hope to use this property to come up with new efficient algorithms.

To do that we will try to use results from scheduling and graph coloration which describe somewhat similar problems but without dealing with the periodicity.

Another problem will be to enrich our modelisation to make it more general, by allowing different bandwidths on the links or to allow to cut the packets into pieces.

[Résumer les résultats du stage]

[Mettre un blabla SDN]

[Mettre un blabla slicing]

In this context, the study program of this project consists in :

1. Given a routing in a network connecting various RRH and BBU, analyzing theoretically the problem of defining a periodic scheduling (complexity, approximability, particular cases) and proposing efficient heuristic algorithms to solve it , in the context of complex networks well beyond those studied in [Ref].
2. Proposing some new routing algorithms to define the set of paths best suited to the resolution of the previous scheduling problem.
3. Benchmarking the proposed algorithms through simulation on the defined instances in comparison with existing architectural solutions.
4. Proposing solutions for an efficient coordination between computed scheduling and computation elements.
5. Extending the solutions to complex cases like dynamical change of the flows between RRH and BBU.
6. Defining methods, procedures and tools needed to perform computed scheduling.
7. Defining SDN based architecture to support the previous methods and procedures, in relation with on going standards.
8. Integrating this architecture within 5G slicing approach.
9. Demonstrating feasibility of the solutions proposed in the context of the 5G and beyond, through simulation and prototype.