Performance Evaluation of CoMP Coordinated Scheduling over Different Backhaul Infrastructures: a Real Use Case Scenario

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***Abstract*—This work studies how cell information distribution for Coordinated Scheduling in Cooperative Multi Point Transmission might be affected by the backhaul infrastructure. Several CoMP schemes are investigated and a novel OSPF based advertisement protocol for CoMP information distribution is proposed. Star topology with centralization at macro cell is shown to be the most convenient choice in terms of both convergence delay and deployment costs. The proposed protocol represents a feasible solution preserving network configurability and management.**

***Index Terms*—RAN, Topology, CoMP, LTE, X2AP.**

I. Introduction

Coordinated Multipoint (CoMP) is a set of techniques to reduce the inter-cell interference and improve cell-edge throughput. Among the CoMP techniques, in coordinated scheduling (CS) user scheduling decisions are made with coordination among the evolved NodeBs (eNBs) belonging to a set of cooperating eNBs (i.e., the CoMP cooperating set). CS between multiple, possibly heterogeneous, cells relies on up-to-date indicators shared between the entities that participate in the decision process [1]. CoMP can be implemented in either a distributed (i.e., D-CoMP) or centralized architecture (i.e., C-CoMP). In D-CoMP each eNB exchanges information with its neighbor eNBs via the X2 interface. In C-CoMP a resource coordinator (RC) is introduced to perform the scheduling. The information is therefore exchanged between the eNBs and the coordinator that, in turn, informs the eNBs of the scheduling decision.

Many studies have investigated what is the optimal size of the CoMP cooperating set in terms of number of eNBs and evaluated the performance improvements provided by CS in terms of cell throughput [2]. Protocols to distribute the relevant information between eNBs in LTE networks are still under study. These techniques are sensitive to the delay required by the cooperating set of eNBs to reach the status where all eNBs share the same knowledge, i.e. the convergence of the cell distribution protocol. However, the impact of the *topology* of the Radio Access Network (RAN) on the performance of CS has not been adequately investigated in either the D-CoMP or C-CoMP scenario. Indeed, the cell information needed for cooperation is sent to neighbors eNBs through the X2 interfaces and the RAN topology determines the convergence delay, thus limiting the effectiveness of CS.

The best gain is provided when up-to-date cell information is used for coordinated scheduling [3]. The timely exchange of messages among eNBs is of extreme importance to reach the expected performance improvement. Actually, a node could make the wrong decision based on obsolete information while the update message has been generated from another node in the cluster but not yet received [3]. Hence, the *convergence delay* that the messages carrying scheduling updates require to reach all eNBs belonging to the cooperating set is the key parameter that determines the performance gain of the adopted CS scheme. Moreover 5G ongoing standardization activities are focusing on a tighter subframe dimension [4] that could strongly influence the design of the appropriate periodicity of scheduling decisions.

This paper provides a performance evaluation of the CoMP CS in the presence of backhaul infrastructures based on the following different topologies:

- a mesh of configurable switches via a Software Defined Network (SDN) controller,
- a mesh of switches running a Spanning Tree Protocol (STP),
- a star and
- a ring topology.

Performance of the CS are evaluated in terms of convergence delay and deployment costs. Both distributed and centralized CoMP coordinated scheduling are considered. Moreover, the role of the *logical topology* adopted at the application layer is investigated. In the distributed scenario, a novel Open Shortest Path First (OSPF) based advertisement protocol is introduced to share CoMP information among network nodes.

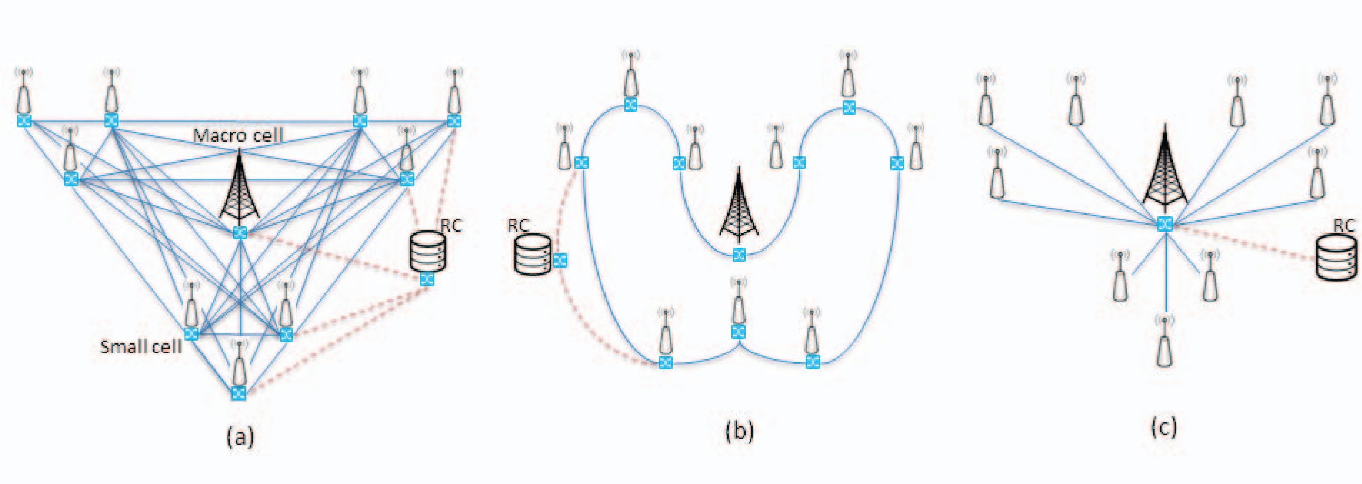

Fig. 1: Different RAN topologies: (a) full mesh, (b) ring, (c) star.

II. System Model

Collaborative scheduling techniques are implemented by eNBs belonging to the same cooperation cluster by exchanging information related to the current or foreseen allocation of Physical Resource Blocks, depending on the adopted coordination scheme. Our work refer to the LTE-Rel-13 X2 Application Protocol (X2AP) [5], hence we assume that nodes exchange Load Information messages containing CoMP information to optimize the resource scheduling in coordination with the cooperating set of eNBs.

The convergence delay of these messages is strongly influenced by the topology of the RAN that interconnects the set of collaborating eNBs. We consider the three different RAN topologies shown in Fig. 1, namely a full mesh of switches each one connected to an eNB (Fig. 1(a)); a chain topology of switches each one connected to an eNB (Fig. 1(b)); and, finally, a star topology where all cooperating eNBs are connected to the same switch(Fig. 1(c)).

In this work we analyze the impact of RAN topology in either centralized or distributed CoMP architectures. With reference to Fig. 1, in D-CoMP the eNBs exchange each other the cell information through the X2 interface. Considering that the X2 topology that results from the instantiation of neighborhood relations among eNBs affects the number of exchanged messages among eNBs, we evaluate the adoption of a logical hierarchy of eNBs where some eNBs serve as collector gateway of the scheduling infrmation that share with the other nodes. This way the broadcast domains in the cluster of collaborating eNBs are separated. In C-CoMP a RC is inserted in the network accordingly to the reference topology. In this case CoMP information is shared within the cluster by the RC, which receives update messages by the cooperating eNBs. The RC is in charge of making scheduling decisions. It is important to mention that in this case the communication takes place using a new defined XN interface instead of ordinary X2 interface.

III. CoMP Information Advertisement Protocol

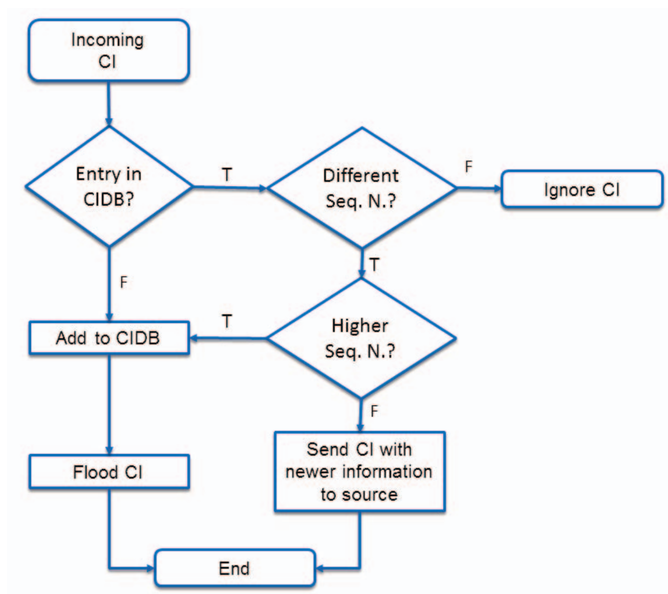

Fig. 2: CoMP Information advertisement protocol.

The adoption of a D-CoMP scheme for CS purpose requires that a logical neighborhood relationship at X2AP layer among all the eNBs in the cooperating set is configured. X2 neighborhood requires the instantiation of a Stream Control Transmission Protocol (SCTP) socket that is the trasport protocol designated for X2 messages exchange and consequent configurations at lower layers for the routing and switching of the X2 traffic. Thus building a complete topology at X2 AP layer could result in excessive network configuration and management complexity. Moreover, considering that other X2 interface functions such as cell assignment and handover could not require the same amount of X2 neighborhood relationships, designing the network taking into account CS could result in

Fig. 3: L'Aquila MAN and small cells deployment.

an over provisioning of transport resources. On the other hand an instantiation of X2 relationships done according only to handover purposes is not adequate to support CS due to the fact that X2 Load Information messages need to be sent to all the eNBs in the cluster.

A suitable approach could be to implement X2 relationship basing on handover needs, i.e. considering physical distances, and to designate an eNB as X2 message gateway towards the other nodes in the collaborating set obtaining a hierarchical topology at X2 layer. This approach requires to adopt a protocol that defines the advertisement mechanisms of the CoMP information in the cluster.

We propose a CoMP information advertisement protocol that is based on OSPF flooding procedure [6]. The assumption on which the proposed protocol is based is that each collaborating node in the cluster periodically advertises its CoMP hypothesis with a periodicty that is equal to an *advertisement interval* i.e. the time that elapses in between two advertisement. During the *advertisement interval* the eNB takes decisions about its scheduling taking into account the CoMP information sent by other eNBs. The advertised CoMP Information needs to be received by all the nodes within the *advertisement interval* so that each node is able to take autonomously decisions using up-to-date information. Every time a new CoMP Information (CI) is generated, a new Sequence Number is associated by the generating node.

As shown in Fig. 2, every time a new CI is received the eNB checks if it already has a CI associated to the cell indicated in the CI. If a CI is already present in the CoMP Information Database (CIDB) it checks if the new information has an higher Sequence Number meaning that is more recent. If this is the case, the received CI is stored in the CIDB in order to be taken into account to compute the scheduling and is flooded to all the neighbors, with the exception of the one from which the message is received. If the received CI is older than the one that is already stored, a new message is sent back to the source containing the up-to-date information.

The adoption of the proposed protocol ensures that, in a hierarchical logical topology, X2 messages are forwarded to all the eNBs in the cluster.

IV. Performance Evaluation

The comparison between the different network topologies has been done by means of simulations in NS3 environment, where we implemented different scenarios by extending the available LTE module [7].

Since the size of the cooperating cluster affects significantly the CoMP gain, as shown in [2], we selected a reference setup composed by a macrocell and three groups of 3 small cells

TABLE I: Network complexity

		Links	Order	Interfaces	Order
Full mesh	Centralized	$\frac{(n+1)(n+2)}{2}$	$O(n^2)$	$(n+1)(n+2)$	$O(n^2)$
	Distributed	$\frac{n(n+1)}{2}$	$O(n^2)$	$n(n+1)$	$O(n^2)$
Star topology	Centralized	$n+1$	$O(n)$	$2(n+1)$	$O(n)$
	Distributed	n	$O(n)$	$2n$	$O(n)$
Ring topology	Centralized	$2(n+1)$	$O(n)$	$4(n+1)$	$O(n)$
	Distributed	$2n$	$O(n)$	$2(2n)$	$O(n)$

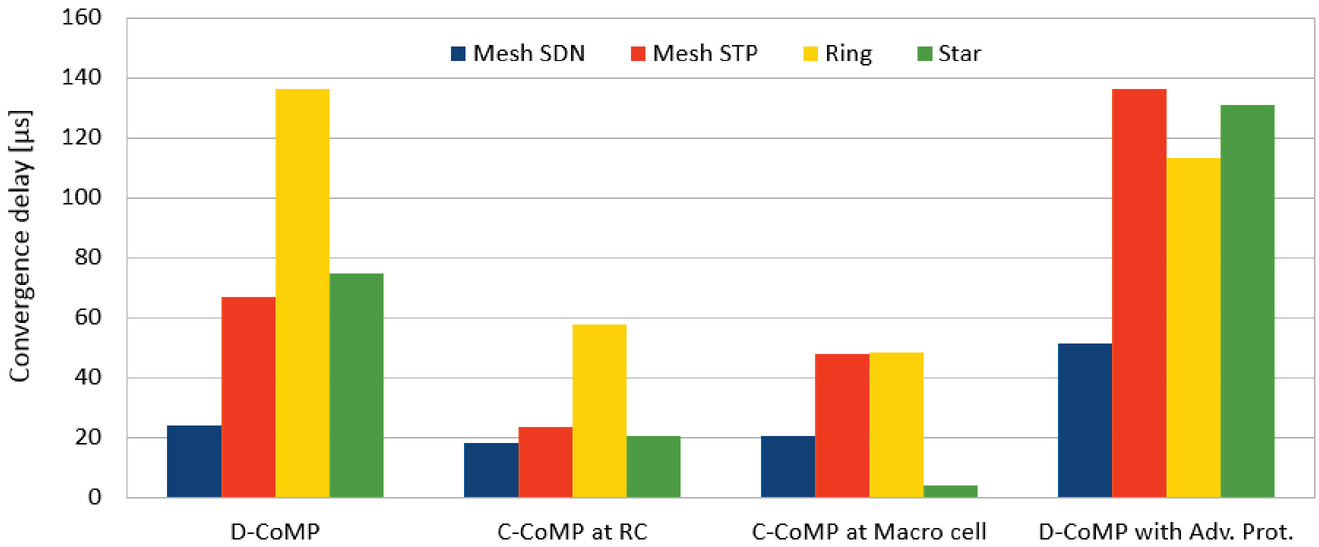

Fig. 4: Convergence delays of the different RAN topologies.

placed at the edge of the macro cell resulting in an average number of 10 cooperating eNBs, interconnected according to the different topologies shown in Fig. 1 through a 10 Gbps Fiber Ethernet links.

We study a real use case scenario that is the future access network of the city of L'Aquila (Fig. 3). The L'Aquila network is under construction and will be based on a MAN architecture consisting of a fiber-optic ring with thirty-one access nodes. In this work we assume to use the optical ring as backhaul infrastructure for macro cells and evaluate a possible deployment of small cells with 50 meters coverage serving three points of interest within the macrocell coverage area at an average distance of 250 meters from the macrocell site.

The exchange of X2AP messages at transport layer adopts the SCTP that does not support multicast transmission. Thus, whenever an eNB has to broadcast Load Information Messages to the nodes of the cluster, it has to generate different messages with a different IP destination address for each collaborating node that has to be treated separately by switching devices instead of being broadcasted to all forwarding interfaces in the switch.

Regarding cooperation schemes we consider four cases:

- D-CoMP, in which all nodes are X2 neighbors between each other,;
- C-CoMP with RC, in which all nodes have a neighborhood relation with a RC placed at inter macro-cell distance;
- C-CoMP with centralization at Macro Cell, in which all nodes have a neighborhood relation with the macro-cell acting as RC;
- D-CoMP hierarchical, in which one node in the small cell groups acts as gateway and the proposed advertisement protocol distributes CoMP information within the cluster.

In hierarchical D-CoMP one node in each small cells group acts as a gateway towards the other nodes in the network. To this purpose we introduced the OSPF based advertisement protocol described in Sec. III.

We evaluate the CS performance using the following metrics:

- the *convergence delay* of the Load Information Message, defined as the time that elapses between the generation of the message in all nodes and the moment in which the message has been received by all collaborating nodes in D-CoMP or the time that elapses between the generation of the message in all nodes and the moment at which a reply from the RC is received by all the nodes in C-CoMP.
- the *complexity of the network topology* in terms of number of required links and connected interfaces (i.e., the *cost deployment*).

Let n be the number of eNBs in the cluster, the complexity of the network is shown in Table I.

V. Results

As schow in Fig. 3, we consider the real use case in L'Aquila as populated by one macrocell and nine small cells constituting ona cluster. The cluster neighbors are interconnected according to the different topologies shown in Fig. 1.

Our analysis shows that in all the considered cooperation schemes the ring topology experiences in average the higher convergence delay, whereas the star topology reaches the minimum (shown in Fig. 4). This can be explained by the fact that in distributed case the number of messages exchanged between eNBs is higher and availability of the links is lower. Thus, increasing the average number of hop indeed increases the convergence delay. The mesh topology involves the highest number of switches with respect to the other RAN topologies.

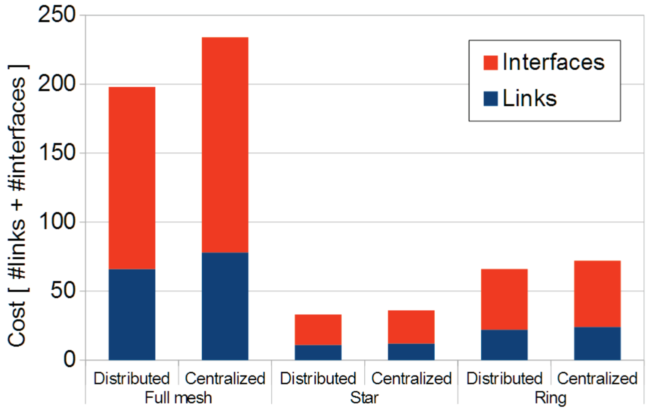

Fig. 5: Costs of the different RAN topologies for D-CoMP and C-CoMP.

Instead, in the star topology all eNBs are attached to the same switch, and the message passes through one switch only to reach its destination.

Fig. 4 also shows that the distributed scheme is convenient in terms of delay only when packets with different destinations can go through different paths at the same time avoiding an increase in queuing and switching time. This requires a topology that makes available a huge number of links, such as the mesh topology. From this viewpoint, centralizing at the macro emerges as an advantageous approach. Our novel hierarchical approach increases the convergence time with respect to the centralization at macro scheme but it represents a reasonable compromise when computational capacity at the macro is not available and a totally distributed X2 instantiation is not preferred.

The SDN approach in mesh physical topology strongly reduces the convergence delay of CoMP information with respect to traditional network running STP. This is explainable by the fact that in a SDN the knowledge of the whole topology is available at the controller, allowing to instantiate optimal routing and switching of flows to reduce the time needed for messages to reach their destination. Consequently, the convergence time of CoMP information is reduced. Instead, traditional networks running STP map network mesh topology into a tree, forcing messages to navigate the tree through a non-optimal path in order to reach their destinations and consequently increasing convergence time.

Concerning the cost metric, shown in Fig. 5, the mesh topology requires a huge number of links and connected interfaces with respect to other topologies, with a high complexity of network management. The minimum cost is achieved by the star topology because it requires just one switch connected to all eNBs. From Fig. 5 it emerges that the C-CoMP architecture is not significantly affected by the RAN deployment cost because it needs only the links and the switches necessary to connect the cooperating eNBs to the RC. The impact is greater for the mesh topology due to the fact that one link per every switch on the network has to be deployed.

The star topology appears as the most convenient choice among the others in terms of both convergence delay of CoMP information and deployment costs. Moreover, in a real scenario where eNBs must collaborate to enhance radio access performance, it is reasonable that interfering nodes are located at short distances, i.e. such as to be connected to the same switch. However, the drawback of the star topology is that it is affected by low failure tolerance that is drastically improved by the full mesh topology.

VI. Conclusions

Our work evaluated the impact of RAN topology on the performance of D-CoMP and C-CoMP. According to Rel-13 X2AP load information messages, each eNB sends CoMP information to all eNBs in the cooperating set or to a RC, respectively. We analyzed the performance of different RAN topologies in terms of convergence delay and deployment costs. Star topology centralized at the Macro represents the best choice. We proposed an advertisement protocol for CoMP information that simplifies X2 configuration and management. Our results shown what are the conditions in which this approach is advantageous.

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