Placement du coeur d'un réseau mobile autonome

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Une station de base isolée est une station de base sans connexion vers un cœur de réseau traditionnel. Une telle station de base doit être autonome pour pouvoir fournir des services aux utilisateurs. Pour cette raison, elle est souvent colocalisée avec une entité lui fournissant, en local, les mêmes fonctions du réseau cœur traditionnel, appelée EPC Local. Pour établir un réseau à large couverture, plusieurs stations de bases doivent être interconnectées et desservies par le même EPC Local. Dans ce travail, nous abordons le problème de placement de cet EPC Local dans le réseau, afin de déterminer la station de base avec laquelle il faut le colocaliser. Nous proposons ainsi une nouvelle métrique de centralité, qu'on appelle centralité de flux, mesurant la capacité d'un nœud à recevoir le flux total dans le réseau. Nous montrons que le fait de colocaliser l'EPC local avec la station de base ayant la centralité de flux maximale permet de maximiser le volume total du trafic que cet EPC local peut recevoir, sous certaines contraintes de capacité et de répartition de charge.

Mots-clefs : Mobile Networks, LTE, Core Network, EPC, Centrality, Function Placement

1 Introduction

The concept of autonomous isolated base stations (BSs), having no backhaul connectivity to a traditional core network (i.e. referred to as Evolved Packet Core (EPC) in LTE), is currently gaining momentum [GGRR14, GPP15]. In order to provide local services to users without backhaul communication, an isolated BS should at least have access to a *Local EPC*. A Local EPC is analogous to the traditional EPC of an LTE network. It provides the same basic functionalities of the latter, in addition to hosting the application servers. However, unlike a traditional EPC, the Local EPC is co-located with the BS [GPP15].

In order to cover wider areas, several isolated BSs must be deployed, forming a network served by a single Local EPC. All those BSs must be able to reach the designated Local EPC, co-located with one of them. Hence, the Local EPC placement problem arises, questioning where should the Local EPC be placed in order to better serve the network. In other words, with which BS must the Local EPC be co-located.

In this work, we tackle the Local EPC placement problem. We argue that a Local EPC should be placed in a way that allows it to receive the maximum traffic from each BS in the network, and vice versa, under certain capacity and load distribution constraints. To that end, we propose a new centrality metric, flow centrality, which measures the capacity of a node in receiving the total amount of flows in the network. Following a comparison with different centrality metrics, we show the loss in the total amount of traffic received by the Local EPC, when the latter is placed on a node not having the maximum flow centrality.

2 The Placement Problem

Network Model - We consider a network of interconnected BSs. As the local EPC is co-located with one of the BSs, the inter-BS links form the backhaul, since they will be responsible of forwarding all data and signaling flows between each BS and the Local EPC, and vice versa [FN15]. Traffic between a BS and the Local EPC is routed either directly, if the Local EPC is at one hop from the BS, or in a multi-hop fashion via the inter-BS backhaul links. We suppose that there is no contention between the backhaul links for resource utilization, and that they have limited bandwidth, limiting the amount of traffic routed on them.

Mathematical Notation - Let $G(V,E)$ be an undirected graph modeling our network, with $n = |V|$ nodes, and $m = |E|$ edges. Each BS is a node of the graph, and the inter-BS links are the graph edges. The BS co-located with the Local EPC serving the network, denoted by d, is the destination node, while all the other BSs are sources. Let $\mathcal{S} = V \setminus \{d\}$, and $\mathcal{T} = \{d\}$ be the set of sources and destinations of G, respectively. To model the inter-BS links with limited bandwidth, we consider graph edges with limited capacities, where $c(u,v)$ is the capacity of an edge $(u,v) \in E$, and $f(u,v)$ the flow through this edge. We denote by $z(v,d)$ the flow that a source node v sends towards the destination node d.

Local EPC placement criteria - The Local EPC must be able to receive (transmit) all the data and signaling traffic generated by (destined to) the BS. Hence, the local EPC placement depends on the amount of traffic routed in the network, which in turn depends on the number of users, or the number of user requests. Furthermore, the limited link capacities set a threshold on the amount of traffic that can be transported. Thus, the Local EPC placement must take into consideration the capacity of the links between the BSs, to ensure that all user signaling and data traffic can circulate in the network without loss. Supposing all BSs in the network send an amount of traffic $\lambda(d)$ towards the Local EPC co-located with node d, we recommend placing the Local EPC in such a way that $\lambda(d)$ is maximized. That means all BSs are capable of forwarding the maximum possible amount of traffic to the Local EPC simultaneously, while respecting the limited link capacities. To this end, we define in Sec.4 the flow centrality metric.

3 State-of-the-art Centrality Metrics

Several centrality metrics were proposed in literature [Bor05]. The **degree centrality** is the number of links the node has with other nodes. While this measure gives an idea on the node connectivity, it does not take into consideration the limited link capacities. The **weighted degree** is equal to the sum of the weights of the links connecting the node to its direct neighbors. While a node with the maximum weighted degree is potentially capable of receiving the maximum amount of traffic, this traffic is not necessarily achievable, due to other limited links. The **closeness centrality** measures how close a node is to all the other nodes. A node with the maximum closeness centrality has a central position. However, the limited link capacities leading to this node limit the amount of traffic it is capable of receiving. The **betweenness centrality** quantifies the number of times a node acts as a bridge along the shortest path between two other nodes. However, link capacities around the node with the maximum betweenness centrality may limit its ability to forward traffic. In the following, we further highlight the inadequacy of these centralities for the Local EPC placement, by comparing them to the flow centrality metric we propose.

4 Flow Centrality

Flow centrality is a novel centrality metric measuring the capacity of a node in receiving the total amount of flows in the graph. The flow centrality of a node is represented by the maximum traffic that can be generated by all the other nodes in the graph, and directed towards this node if it were the only destination. To compute the flow centrality of node d, it is sufficient to compute the maximum amount of flows that node d can receive from all the other nodes in the graph. The total flow value received at node d is : $|f|_d = \sum_{v \in \mathcal{S}} z(v,d) = (n-1) \cdot \lambda(d)$.

We denote by $\bar{\lambda}(d)$ the maximum achievable value of $\lambda(d)$. The value of $\bar{\lambda}(d)$ is obtained through the maximization problem of $\lambda(d)$ (Eq. 1), subject to the following constraints : all sources in the graph have a fixed supply equal to $\lambda(d)$ (Eq. 2) ; the flow on each edge in the graph must not surpass the edge capacity (Eq. 3) ; the flow entering a node must be equal to the flow exiting a node (Eq. 4) ; the total flow value received at the sink is equal to the sum of all the supplies of the sources (Eq. 5).

When the supply $\lambda(d)$ is maximized, the total flow received at d is also maximized, such that :
$|f|_{d_{max}} = (n-1) \cdot \bar{\lambda}(d)$. Eventually, the flow centrality of a node d is defined as $\bar{\lambda}(d)$.

The maximum flow centrality is $\lambda_{max} = \max_{d \in V} \left(\bar{\lambda}(d)\right)$. Practically, this new metric distinguishes the node that, when set as destination, receives the largest amount of flows in comparison to when other nodes are set as destination. Hence, in order to optimally serve the network, the Local EPC must be co-located with the node v having the maximum flow centrality, such that $\bar{\lambda}(v) = \lambda_{max}$.

$$\underset{\lambda(i)\in[0,\infty)}{\text{Maximize}} : \lambda(d) \tag{1}$$

$$\text{subject to} \quad z(v,d) = \lambda(d),\ \forall\ v \in \mathcal{S} \tag{2}$$

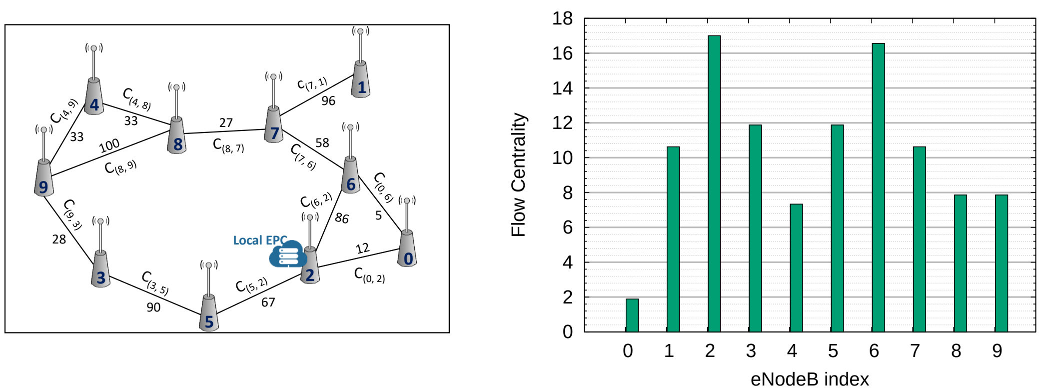
$$f(u,v) \leq c(u,v),\ \forall\ (u,v) \in E \tag{3}$$

$$\sum_{u\in\mathcal{S}} f(u,v) = \sum_{w\in\mathcal{S}} f(v,w),\ \forall\ v \in \mathcal{S} \tag{4}$$

$$\sum_{v\in V} f(v,d) = (n-1)\cdot\lambda(d) \tag{5}$$

4.1 Numerical Example

We show, in Fig. 1a, an example of a network topology, with 10 BSs served by a Local EPC. Link capacities are randomly distributed such that $c \in [1,100]$. We compute the flow centrality value of each node of this network using the CPLEX software package. Since the number of nodes is relatively small, the overall computation time is in the order of of milliseconds. This small number of nodes corresponds to the nature of such networks, where only few BSs are needed. Fig. 1b shows the flow centrality value $\bar{\lambda}(d)$ of each node d of the network. Results show that node 2 has the maximum flow centrality. This means that, by co-locating the Local EPC with BS 2, all BSs are capable of sending towards the Local EPC a traffic equal to $\bar{\lambda}(2)$.



(a) Network topology.

(b) Flow centrality values.

FIGURE 1: An example of flow centrality in a network.

5 Benchmarking Flow Centrality

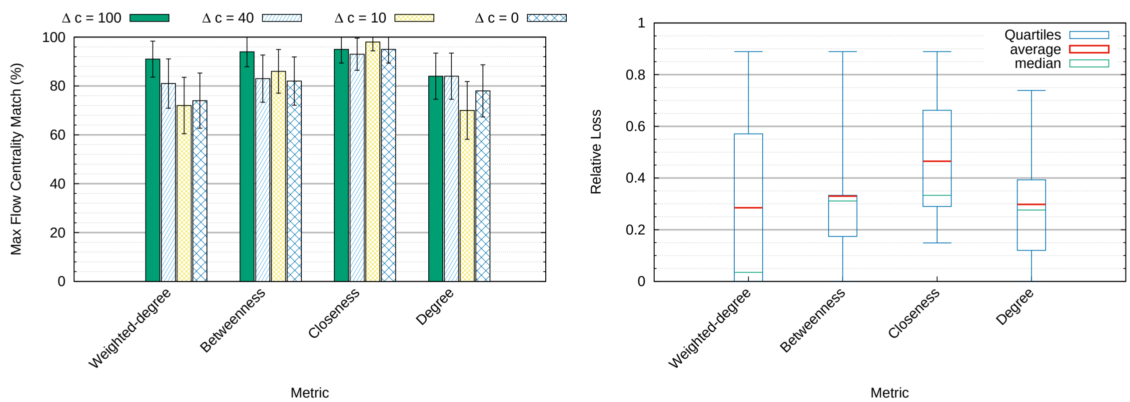
In this section, we compare the flow centrality with the other centralities presented in Sec. 3. We are mostly interested in checking if the node having the maximum flow centrality is the same as the node maximizing one of the other centralities. To compare with the state-of-the-art centralities, presented in Sec.3, we compute the traffic loss incurred if the Local EPC was placed on a node maximizing one of the centralities, but not the flow centrality. If λ_{max} is the maximum flow centrality in the graph, and $\bar{\lambda}(u)$ is the flow centrality of a node u, then placing the Local EPC on node u will cause a relative traffic loss $\varepsilon_{\lambda}(u)$, such that :

$$\varepsilon_{\lambda}(u) = \frac{\lambda_{max} - \bar{\lambda}(u)}{\lambda_{max}} \tag{6}$$

We consider different random graph topologies, with random link capacities such that $c \in [c_{min}, c_{max}]$. We denote by $c_{avg} = \frac{c_{min}+c_{max}}{2}$ the average link capacity, and by $\Delta c = c_{max} - c_{min}$ the capacity range. We fix c_{avg} to a constant value, and vary Δc, in order to study its effect on the position of the node with the maximum flow centrality. All the following results are averaged on a sample of 100 random geometric graphs with 10 nodes, with confidence intervals at 95%.

In Fig. 2a, we show the percentage of generated topologies where the node with maximum flow centrality is identical to the nodes maximizing the other centrality metrics. We can notice that, even with uniform link capacities, i.e. $\Delta c = 0$, the node with the maximum flow centrality can be different from the nodes that maximize the other centralities. Results show that the closeness centrality is the closest to the flow centrality in terms of matching percentage. For example, for $\Delta c = 100$, the node with maximum flow centrality is identical to the node with the maximum closeness centrality in 95% of the cases. We note that the capacity range Δc does not have a significant effect on the matching percentage.

In Fig. 2b, we show the relative traffic loss ε_λ (Eq.6) when the Local EPC is not placed on the node with the maximum flow centrality. Even though nodes with maximum closeness centrality had the highest matching percentage with the nodes with maximum flow centrality, the average traffic loss incurred when these nodes are different is relatively high. As shown in Fig. 2b, placing the Local EPC on the node with the maximum closeness centrality instead of the node with the maximum flow centrality would cause a relative traffic loss of 46.5%, which is the highest loss in comparison with the other centrality measures. The relative losses incurred by the other centralities are lower, but still important, around 30% on average.



(a) Percentage of topologies where the node with maximum flow centrality is identical to the nodes maximizing other centralities

(b) Relative traffic loss when the Local EPC is placed on the node maximizing centrality metrics other than flow centrality.

FIGURE 2: Comparison of nodes with maximum flow centrality to nodes maximizing other centrality metrics.

6 Conclusion

In this paper, we tackled the placement problem of a Local EPC serving a network of BSs with no backhaul connectivity. We proposed flow centrality, which is a novel centrality metric. Placing the Local EPC with the BS having the maximum flow centrality maximizes the total amount of traffic that the Local EPC is capable of receiving from all the BSs. Treating the BSs in the network equally, by uniformly maximizing their capabilities, is suitable for a network where the Local EPC is statically planned, and remains fixed. However, for future work, non-uniform BS demands must also be considered. Furthermore, end-to-end delay constraints must be further included in the Local EPC placement criteria.

Références

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