Coordination protocol for inter-operator spectrum sharing based on spectrum usage favors

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***Abstract*—Currently, mobile network operators are allocated spectrum bands on an exclusive basis. While this approach facilitates interference control, it may also result in low spectrum utilization efficiency. Inter-operator spectrum sharing is a potential method to enhance spectrum utilization. In order to realize it, a protocol to coordinate the actions of operators is needed. We propose a spectrum sharing protocol which is distributed in nature, it does not require operator-specific information exchange and it incurs minimal communication overhead between the operators. Operators are still free to decide whether they share spectrum or not as the protocol is based on the book keeping of spectrum usage favors, asked and received by the operators. We show that operators can enhance their QoS in comparison with traditional orthogonal spectrum allocation while also maintaining reciprocity i.e. no operator benefits over the other in the long run. We demonstrate the usability of the proposed protocol in an indoor deployment scenario with frequent network load variations as expected to have in small cell deployments.**

I. Introduction

To meet the increasing data traffic demand in a timely manner, a viable solution is a shared use of radio frequency (RF) spectrum where multiple independent users can utilize the same RF resources provided that they do not generate destructive interference to each other [1]. Shared spectrum use between mobile network operators has significant business potential particularly in small cell deployments. For the time being, spectrum is exclusively assigned to the operators. In a more flexible regulatory world, it is envisioned that operators may agree to let other operators use their spectrum. For instance, different operators can provide high speed data access at different parts of shopping malls. In that case, inter-operator interference is low and operators can entertain the benefit of higher available bandwidth without disturbing each other.

A coordination protocol is a distributed method to enable spectrum sharing between peer networks [2]. It requires a logical connection between the different networks e.g. over-the-air, via the core network, etc. Existing coordination protocols for inter-operator spectrum sharing assume either operator-specific information exchange or that operators agree beforehand on some spectrum allocation which is maintained under the threat of punishment. These attributes can be problematic because on the one hand, operators are competing entities and on the other, under frequent network load variations static spectrum allocation has poor performance.

Operators are expected to share spectrum for a long time. Due to the fact that an operator has a persistent and publicly known identity, the operators can learn from each other's behavior.

We propose a coordination protocol that realizes spectrum sharing by means of a virtual monetary economy [3] based on a rudimentary currency in terms of spectrum usage favors, asked and received by the operators. In this perspective, operators are free to decide whether they take part into the spectrum usage negotiations or not. According to the proposed protocol, operators with low load fulfil spectrum usage favors to heavily-loaded operators. Operators are needed to maintain the reciprocity, and the operators with granted favors in the past will return these favors in future. In this way, all operators offer better QoS in comparison with static spectrum allocation without revealing their specific performance indicators nor making any agreement beforehand.

II. Proposed coordination protocol

Let us assume that an operator can construct a number that describes the QoS offered to its users. This kind of number is usually referred to as network utility. The network utility function can, for instance, be defined as a linear combination of average and cell edge performance. Note that the proposed coordination protocol does not require that the operators employ the same utility function nor that the operators are aware of each other's utility function.

Before asking/granting a favor, an operator has to evaluate the effect the opponent operator has on its utility. In order to do that an operator should measure the amount of interference it receives from the opponent. For downlink transmissions, this functionality can be a simple extension of LTE handover measurements. For example, the operator may ask its users to measure on the interfering signal levels and report them to the serving base station. Note that this kind of functionality does not require any signaling between serving and interfering base stations, as in the regular handover procedures.

For different spectrum sharing scenarios there should be different types of spectrum usage favors asked and taken among the operators. According to the limited spectrum pool scenario, there is a shared pool of resources available to use by a certain number of users [4]. With limited spectrum pool we view a single type of spectrum usage favor:

- Operator asks the opponent operator for permissions to start using a resource from the pool on an exclusive basis.

In a mutual renting scenario, each operator owns exclusively a certain amount of resources but there can be mutual agreements between operators for resource utilization. In that case we view two different kind of spectrum usage favors:

- Operator asks the opponent operator for permission to start using one of the opponent's resources.
- Operator asks the opponent operator for permission to start using one of the opponent's resources on an exclusive basis.

In general, the spectrum usage favor should be granted for a certain time interval that has to be agreed among the different entities. During that time interval, the operators do not renegotiate the usage of that particular resource. After that

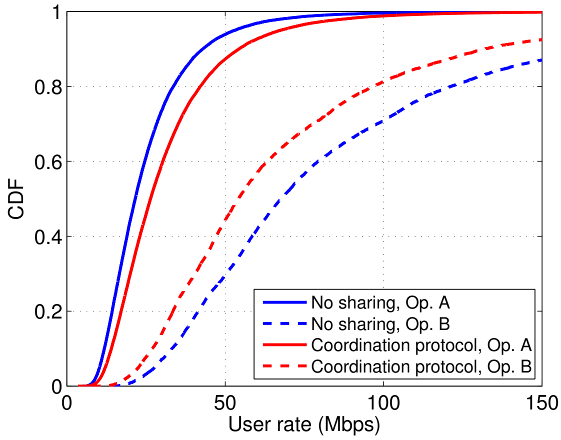

Fig. 1: Rate distribution for Operator A with higher mean load and Operator B with lower mean load using orthogonal spectrum sharing and the coordination protocol in a limited spectrum pool scenario.

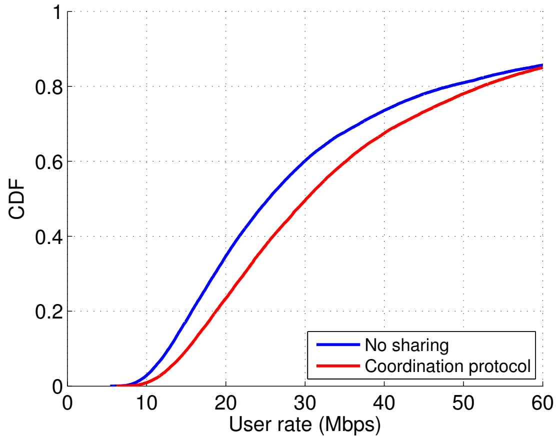

Fig. 2: Rate distribution for Operator A with load variations using orthogonal spectrum sharing and the coordination protocol in a limited spectrum pool scenario.

interval, the resource allocation falls back to the state it had before granting the favor, i.e. in limited spectrum pool both entities should utilize the resource and in mutual renting the entity granting the favor can start using the resource on an exclusive basis.

Operators are self-interested entities. They will ask/grant a favor only if, in the long run, they expect to get more benefits than losses. To do so, one way is to investigate the history of previous interactions with the opponent operator and accordingly take the actions. For example, before asking for a favor, the operator checks whether its immediate utility gain is larger than its average utility loss over the history of previous interactions. In a similar manner, an operator grants a favor only if its immediate utility loss is smaller than its average past utility gain. In order to maintain reciprocity, operators should grant about the same number of favors over the time. For that purpose, we define a positive integer number S that determines the maximum allowable number of outstanding favors.

Overall, the proposed decision making process avoids immediate punishment and it is also forgiving, resembling an extended time period tit-for-tat retaliation strategy [5]. As soon as the opponent starts granting favors again, the operator would also be willing to cooperate and grant favors back.

Before illustrating the usability of the proposed protocol, we note few more aspects which are not treated in this work. In general, spectrum usage favors can be of different priorities. For example, when an operator cannot meet its QoS, it may add a high priority in the favor it asks for and subsequently, provided that the favor is granted, it will also get a high penalty in the future due to the priortized favors it has received in the past. Also, operators can ask/grant favors for a variable time interval which should be optimized taking into account the history of previous interactions and the traffic model. We leave such kind of protocol features for later study. In this paper, we consider spectrum usage favors of equal priority which are valid for a fixed time interval.

III. Results

We consider a deployment scenario with two operators, Operator A and Operator B coexisting in spectrum and offering high speed data services at different parts of a single-story building. Each operator is allocated one component carrier to ensure coverage while there are also six component carriers belonging to a shared spectrum pool. We consider a scenario with high inter-operator interference and load asymmetry. We evaluate the performance of the proposed coordination protocol over a finite time horizon with 1000 different deployment snapshots. Rest of the parameter settings can be found in [4].

In Fig. 1 the rate distributions for the users of Operator A and Operator B are depicted, when Operator A has a higher mean load than Operator B. In this scenario, Operator A receives more favors than Operator B. In Fig. 2, the rate distributions for the users of Operator A are depicted over the full simulation time, where the operator experiences both high and low load states. Operator A has received more component carriers, when it has high load during the course of simulation. Overall, better QoS may be offered when using the coordination protocol, than with static orthogonal sharing. The user rate distribution curves for Operator B follow the same trend.

Acknowledgment

This work has been performed in the framework of the FP7 project ICT 317669 METIS, which is partly funded by the European Union.

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