Analysis of Integrated Cellular and Ad hoc Relay Systems
(Sponsor: NSF)

Although cellular systems were introduced to enable communication between subscribers whenever needed, the extraordinary increase in demand for mobility and, hence, the increase in the number of subscribers and wireless traffic over the last decade makes it difficult to meet this objective. The wireless service providers have to cope with the problem of limited spectrum to meet the increased demand of mobile users. Therefore, in a cellular network, efficient allocation of resources (channels) to each cell is of great importance. This problem becomes even more crucial when some cells in the system are congested or hot, i.e., the traffic generated by the subscribers is more than the capacity of the service provider’s infrastructure. This means that the grade of service (GoS) in those cells may go down to a level below a prescribed threshold (e.g., the call blocking probability in those cells goes above 2%).

It is well-known that the hot spot problem can be solved by dynamically balancing the load of the hot cells in cellular networks, either by borrowing channels from the cooler (non-congested) cells in the system such as simple borrowing or channel borrowing without locking, or by forwarding the excess traffic of the hot cell to the cooler cells, such as directed retry. Integrated Cellular and Ad hoc Relay (iCAR) system is a recently proposed dynamic load balancing scheme, where an overlay ad hoc network is employed to balance traffic loads efficiently and to share channels between congested and non-congested cells in the cellular network.

Basically, in an iCAR system, a number of ad hoc relay stations (ARS’s) is placed throughout the geographical coverage area, so that the signals between the mobile hosts (MH’s) and base transceiver stations (BTS’s) can be relayed, and an MH requesting service in a hot cell can communicate with the BTS’s of the cooler neighbors of the hot cell. An ARS is assumed to be a wireless communication device, which may have limited mobility under control of a mobile switching center (MSC), and it can communicate directly with an MH, a BTS, or another ARS through air interfaces. Each ARS and MH is assumed to have two air interfaces, one for communicating with the BTS’s (cellular interface) and the other for communicating with the MH’s and other ARS’s (relay interface). It is also assumed that the ARS’s use 2.4 GHz unlicensed ISM band channels, while relaying the signal of the MH’s and other ARS’s. The basic relaying mechanisms through ARS’s can be described as follows:

**Primary Relaying**: If an MH cannot be assigned a voice (or data) channel in a congested cell, it can be directly relayed to a neighboring cell via ARS’s if the MH is within the ARS coverage area. For example, assuming that cell 2 in Fig. 1 is congested, a new user X will not be able to find a cellular-band channel in cell 2. However, since it is in the coverage area of ARS2, it can use a channel of cell 1 via primary relaying through ARS2.

**Secondary Relaying**: If the MH requesting service is outside the ARS coverage area of the congested cell, an ongoing call within the ARS coverage can be relayed to a neighboring cell via ARS’s freeing up a voice (or data) channel in the congested cell to serve the new call. For example, in Fig. 1, a new user Y cannot be assigned a channel in
the congested cell 2 and it is not covered by an ARS. In this case, checking if there are any ongoing calls within the ARS coverage area, one realizes that user Z is in the coverage area of ARS2. User Z is then relayed to cell 1, and user Y can then use the channel released by user Z in cell 2.

Our project focuses on the analysis of the iCAR systems. To this end, we developed an analytical framework leading to closed-form performance expressions for new call blocking and handover dropping probabilities in terms of the main system parameters. More specifically, our research shows that:

- The new call blocking and handover dropping probabilities decrease:
  - with increasing ARS coverage area and/or
  - with increasing number of ISM-relay channels
- There is a threshold value for both parameters beyond which performance cannot be improved. Our results show that with a significantly low ARS coverage (e.g., 30% of the cellular coverage area) and low number of relay channels (e.g., 10 channels when cellular-band channels per cell is 50), an improvement up to 80% can be achieved in blocking/dropping probabilities.
- Relaying excess traffic to cooler cells does not degrade the performance of the cooler cells.

Our future focus is concentrated on studying the impact of employing ad hoc overlay systems in next generation heterogeneous wireless networks.

REFERENCES