# Quality of Coverage: A New Concept for Wireless Networks*

H. Wu and C. Qiao

Dept. of Computer Science and Engineering

State University of New York at Buffalo, Buffalo, NY 14260

In a cellular system, frequency reuse in the cells far away from each other increases the effective amount of resources. But at the same time, the cell boundaries prevent the channel resource of a cell from being accessible to users in another cell.

In our previous work [1], we have proposed a novel wireless system called iCAR (integrated Cellular and Ad hoc Relaying) which allows a Mobile Host (MH) to use a channel available in a nearby cell (in addition to the cell it is located in). This is accomplished by relaying the data between the MH and the BTS in the nearby cell through ad hoc relaying stations (ARS's) which are placed at strategic locations. For example, in the previously proposed seed growing approach [1], some ARS's are placed as seeds around cell boundaries, and others grow from them (see Figure 1(a)). By using ARS's, it is possible to divert traffic from one (possibly congested) cell to another (non-congested) cell. This helps to circumvent congestion, and makes it possible to maintain calls involving MH's that are moving into a congested cell, or to accept new call requests involving MH's that are in a congested cell. In addition, the ARS's can, in a flexible manner, extend cellular system's coverage, and provide interoperability between heterogeneous systems.

One critical issue is ARS placement as iCAR's performance improvement over a conventional cellular system is largely due to its ability to relay traffic from one cell to another. In this work-in-progress aimed at quantitatively evaluating ARS placement strategies, we introduce the concept of a new performance metric called quality of (ARS) coverage (QoC), whose value ($Q$) is defined to be the amount of *relay-able traffic* in an iCAR system, and present preliminary analytical results on the comparison between various ARS placement strategies. Note that, $Q$ is not always proportional to the ARS coverage. For example, the $Q$ values of ARS 1 and ARS 2 in Figure 1(a) are zero because they cannot relay any traffic between cells although they do cover a certain amount of traffic. Only when an ARS can reach directly or indirectly (via relaying through other ARS's) more than one BTS's, it has non-zero $Q$ value, which is the amount of traffic covered by the ARS minus the part which will be blocked by the reachable BTS's.

In the following discussion, we will consider a cell $A$ in Figure 1(a) with time-averaged traffic intensity $T_A$, which has six neighboring cells with the same (time-averaged) traffic intensity $T_B$. For simplicity, we assume the traffic is uniformly distributed in each cell, and $T_A > T_B$. We first discuss two possible approaches to place the seed ARS, i.e. the border placement approach and the vertex placement approach (see ARS's 3 and 4 in Figure 1(a) respectively). Assuming $S$ is the coverage of an ARS, and let $M = 50$ be the number of Data Channels (DCH's) in each cell, and $b_A$ and $b_B$ be the blocking probability without relaying in cell $A$ and cell $B$ respectively, we have the following equations for the $Q$ values of the two approaches.

$$Q_{Border} = \frac{S}{2} \cdot T_A \cdot (1 - b_B) + \frac{S}{2} \cdot T_B \cdot (1 - b_A) \qquad (1)$$

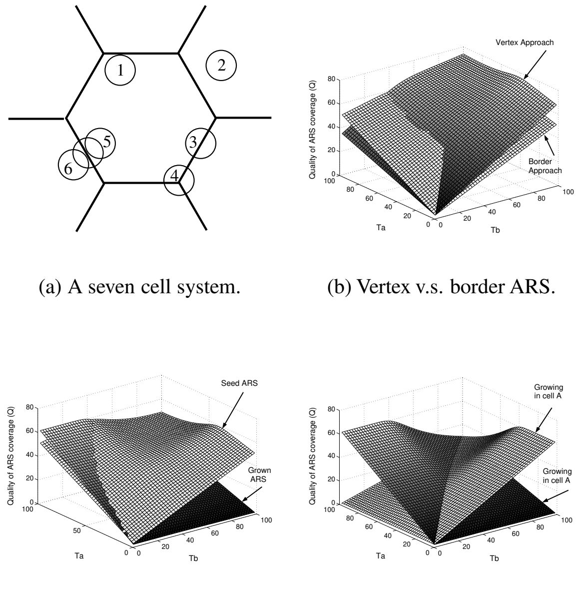
$$Q_{Vertex} = \frac{S}{3} \cdot T_A \cdot (1 - b_B^2) + \frac{2S}{3} \cdot T_B \cdot (1 - b_A \cdot b_B) \qquad (2)$$

As shown in Figure 1(b), when $T_B < T_A < 60\ Erlangs$, the border placement approach is better. Note that, $60\ Erlangs$ corresponds to about $21.6\%$ blocking probability which is much far beyond the normal operation range. Thus, we may have **Rule of Thumb 1**: *Place the seed ARS's at the cell borders.*

If additional ARS's are available, they may either serve as seeds without causing overlap with existing ones, or grow from the existing seeds (see ARS 5 shown in Figure 1(a), assuming the border placement approach is adopted). The grown ARS is required to be within the coverage of at least one existing ARS so that they can relay traffic to each other. Accordingly, the increased $Q$ value due to the grown ARS, assuming it is located in cell A, is about

$$Q_{Grow\_in} \approx 0.61 \cdot S \cdot T_A \cdot (1 - b_B) \qquad (3)$$

where $0.61 \cdot S$ is the area covered by the grown ARS but not covered by any other existing ARS's. This value is compared with $Q_{Border}$ in Figure 1(c), which shows that only when $T_B$ is very low and $T_A$ is much higher than $T_B$, the grown ARS approach performs better than the seed ARS approach. Thus we have **Rule of Thumb 2**: *Place an ARS as a seed if it is possible.*




(a) A seven cell system. (b) Vertex v.s. border ARS.

(c) Seed v.s. grown ARS's. (d) The direction to grow.

Figure 1: The quality of ARS coverage.

If additional ARS's cannot be placed as seeds without causing too much overlapping with the existing ARS's, they can grow from the existing seeds. An ARS can grow either inward or outward cell A (see ARS's 5 and 6 in Figure 1(a), respectively). Since the two growing directions cover area $S$ with different traffic intensities, they may result in different $Q$ values. More specifically, when an ARS grow inward cell A, its $Q$ value is shown in Equation 3. When an ARS grows outward cell A, its $Q$ value is

$$Q_{Grow\_out} \approx 0.61 \cdot S \cdot T_B \cdot (1 - b_A) \qquad (4)$$

It is clearly shown in Figure 1(d) that the ARS grown inward the cell with higher traffic intensity has a higher $Q$ value. Thus, we have **Rule of Thumb 3**: *Place (or grow) an ARS in the cell with high traffic intensity.*

The above three rules of thumb may serve as the guidelines for ARS placement. More specifically, to optimize the system performance, the operators may first place ARS's at the shared borders of the cells, and let additional ARS's grow in the cell with a higher traffic load. We hope that the concept of QoC along with these guidelines will be useful not only for managing ARS's placement in iCAR, but also for planning of and routing in, sensor network, and other wireless networks involving mobile devices such as mobile gateways or satellites.

## References

[1] H. Wu, C. Qiao, S. De, and O. Tonguz, "Integrated cellular and ad-hoc relay systems: iCAR," *IEEE Journal on Selected Areas in Communications special issue on Mobility and Resource Management in Next Generation Wireless System*, Oct. 2001. Edited by Prof. Ian F. Akyildiz, Prof. David Goodman and Prof. Leonard Kleinrock. To appear.

* This research is in part supported by NSF under the contract ANIR-ITR 0082916.