I. INTRODUCTION

Various wireless technologies and systems have been developed over the years, and all signs are indicating that many more are yet to come. The emergence of these heterogeneous wireless technologies calls for the ubiquitous and integrated wireless infrastructures to make the communication system robust and efficient. Recently, a representative integrated wireless system called integrated Cellular and Ad hoc Relaying (iCAR) has been introduced in [1] to address the congestion problem due to limited bandwidth in a cellular system. In iCAR, a mobile host (MH) located in the congested cell A is allowed to use the channel available in a neighboring non-congested cell B. This is accomplished by establishing a relaying route between the MH in cell A and the Base Transceiver Station (BTS) in cell B through the so called Ad hoc Relaying Stations (ARSs). Although the exact location of the MH in cell A does not matter to the success of relaying, the MH must be covered by a nearby ARS (with a limited transmission range) that can communicate with BTS B either directly or indirectly through other ARS’s.

Intuitively, in iCAR, having more ARSs to increase the relaying coverage may facilitate more calls to be relayed from a congested cell to a non-congested cell, which in turn leads to a better grade of service (GoS) (i.e., lower call blocking probability). But on the other hand, more ARSs result in a higher system cost. Clearly, for a given number of ARSs, the effective ARS coverage can be increased by allowing ARSs to move so as to adapt to the dynamically changing locations of the relaying requests. In this paper, we explore the novel ways to increase the effective ARS coverage by managing the mobility of ARSs. Note that certain practical constraints (to be discussed later in this section) may limit the ARS’s movement and consequently the increase in its effective coverage.

Introducing ARS mobility makes the iCAR system more like an ad hoc network. But note that, an ARS differs from an MH in that the former is deployed, used, and controlled by the system only, not by the end users. In other words, the ARSs coordinate with each other and form a special controlled ad hoc network, laid over on the existing cellular system. Accordingly, we will refer to the ARS mobility as managed mobility, to distinguish it from the MH’s mobility which has been extensively studied in the context of ad hoc networks and wireless cellular systems. The ARSs with managed mobility is called Mobile ARS or MARS. To the best of our knowledge, no prior work is available that deals with such managed mobility.

The MARS’ mobility can be classified into two categories: macro-mobility and micro-mobility. With managed macro-mobility, an off-duty ARS (i.e., one that is not relaying any calls) can move a long distance (e.g., through several cells) to a location deemed more desirable by certain ARS placement strategies similar to those discussed in [1]. On the other hand, with managed micro-mobility, an active ARS (i.e., one that is relaying one or more on-going calls) can move only within a short range so as not to drop any on-going connections while still being able to relay a new or handoff call which otherwise would be blocked or dropped. In this paper, we will focus on the managed micro-mobility of MARSs.

II. ARS MICRO-MOBILITY MANAGEMENT

The micro-mobility of the MARS is applied to the scenario where the MHs (for example, in/around coffee shop, shopping mall, stadium, etc.) are primarily static, or even they can move, the moving speed is low and the moving distance is limited. We assume that the MARSs are initially placed at certain positions (according to some placement strategies). More specifically, these MARSs are grouped into clusters, and in each cluster, there is a seed MARS placed at the shared border of two cells, and additional MARSs may grow from the seed so as to cover the MHs far away from the cell border. Without loss of generality, we label the MARSs in a cluster located in one cell with a sequence of consecutive and increasing integers starting with the seed MARS.

An important practical constraint of micro-mobility is that the movement of an MARS should not break any existing connections. For example, if the MARS is a seed, then it still have to be a seed after moving (implying that it may only move along the shared border of two cells). Otherwise, after the seed moves, for example, into cell A, the entire cluster (including ARS 1 and 2) will not be able to relay any traffic from cell A to cell B. In contrast, a grown MARS can move in any directions as long as it is still connected to its upstream node (i.e., the neighbor MARS closer to the seed) after it moves. Of course, this may require its downstream MARSs to move accordingly. In general, we want each MARS to remain in its cluster and to have relaying capability.
We assume that all of the mobile nodes in an iCAR system, including the MHs and the MARSs, may obtain the location information from the Global Position System (GPS) or the local location systems. The MARSs will periodically report their status including the location information to an ARS Mobility Controller (AMC) which can be co-located with the Base Station Controller (BSC). Each MARS maintains the current positions of the MHs to which it is providing the relaying service as a proxy. But, it does not send such information to AMC. Since there are only a limited number of ARSs, the AMC will not be over-loaded by the signaling overhead or become the bottleneck. In an alternate approach, an AMC can maintain all the information about the MARSs and MHs that are receiving relaying service. But such a centralized control approach may not be scalable. Since the distance between a pair of active MARS and an MH is usually short, we assume the line of sight signals are available, and accordingly the communication links can be estimated from the physical distance.

In the rest of this section, we discuss the micro-mobility management strategies for accommodating a relaying request, which is generated by (or on behalf of) an MH X in a congested cell after MH X fails to acquire a data channel in the cell for a new call (or handoff call). Such a relaying request may be satisfied by either primary relaying or secondary relaying without requiring any MARS movement as discussed in [1]. However, if both of them fail, AMC will try primary movement (in analogy to primary relaying) first, and then secondary movement if necessary, as to be described below.

1) Strategies For Primary Movement: The objective of the primary movement is to move a relaying capable MARS close enough to the MH requesting for the relaying service so as to provide primary relaying. We will first present the basic strategy for managing the primary movement, and then discuss possible extensions for further improved performance.

Basic Strategy

Using the basic strategy for primary movement, after receiving the Move_Req from the MH X which includes the MH’s location information, AMC will find the closest MARS (e.g., MARSi) to MH X based on the locations of the MH and the nearby MARSs. AMC determines the destination to which MARSi will try to move (in order for it to become a proxy) by drawing a circle with the position of the MH to be the center and R to be the radius. We will refer to the circle (shown as a dashed circle in Fig. 1 (a) and (b)) as the destination circle, or D-circle. If MARSi is a seed along the shared border of two cells denoted by line AB (see Fig. 1 (a)) and the D-circle intersects line AB at two points, the intersection point closer to MARSi, denoted by H, is chosen as the destination (see Fig. 1 (a)). In such a case, the moving destination of MARSi is found. If MARSi is not a seed (see Fig. 1 (b)), it can move within the circle (to be referred as the S-circle) centered at MARSi−1 with a radius of R, so that it can still be connected to the seed after moving. Accordingly, AMC finds the intersection points of the D-circle and the S-circle, and choose the intersection point closer to MARSi as the destination (see point H in Fig. 1 (b)). In either case above, if there is no intersection points (or tangent point) between the D-circle and the line AB, or between the D-circle and the S-circle, no further actions will be taken, except that a NAK message will be sent to MH X in the basic mobility management approach. (Nevertheless, in such as a case, the extended approach to be discussed later in this subsection may be employed).

After the moving destination is determined, AMC will compute the moving distance of MARSi to be $d_i = |O \leftrightarrow H|$ where O is the initial position of MARSi (see Fig. 1 (a) and (b)), and MARSi’s moving time $T_{mi}$ (e.g., based on $d_i$ and the MARSi’s moving speed). If $T_{mi}$ is larger than the maximum delay budget t allowed for the movement of one MARS, a NAK message will be again sent to MH X. Otherwise, AMC will compute the destination of the next hop MARSi+1 by drawing a line connecting the new position of MARSi (i.e., point H) and the current position of MARSi+1 (see O in Fig. 1 (c)), and choose the intersection point of this line and the circle centered at H (e.g., point H’ in Fig. 1 (c)) to be the moving destination for MARSi+1. Note that, the moving distance (thus the moving time) of MARSi+1 will not be longer than that of MARSi. More specifically, we have the following proposition.

**Proposition 1:** If the moving distance of MARSi (which is not the last MARS in its cluster) is $d_i$, then the moving distance of MARSi+1 ($d_{i+1}$) is not longer than $d_i$.

**Proof:** Omitted.

Similarly, AMC will compute the destinations of other downstream nodes of MARSi, i.e., from MARSi+2 to the last hop of this cluster MARS (where N is the number of MARSs in this cluster, and multicast a Probe message containing the destination information to each of these MARSs. After receiving the Probe message, each MARS will check if any on-going connections would be broken based on its destination and the current locations of MHs to which it provides relaying service (i.e., serves as a proxy). In case of potential drop of existing connection due to its movement, an NAK message will be sent to AMC. Otherwise, the MARS will send an ACK message to AMC. If AMC receives at least one NAK, it will send a Move_Cancel messages to the MARSs and no further actions will be taken. When AMC receives ACK messages from all these MARSs, it will send a Move_Order message to them. After receiving the Move_Order message, the MARSs (including MARSi to MARS ) can start moving. Upon arriving at its destination, MARSi will send an ACK message to MH X and accordingly, MH X will perform a primary relaying.

In an alternative approach, instead of multicasting the Probe message to all related MARSs, the AMC can send it to MARSi only, which will check the on-going relayed connections and forward the Probe message to the next hop (MARSi+1) if none of the on-going connections would be dropped due to the movement, or send a NACK to AMC otherwise. Similarly, other MARSs will check their existing connections and forward the Probe message hop by hop. This approach may reduce the signaling load at AMC, but it will result in a longer delay.

When deploying the basic approach, the computing com-
plexity at the AMC and an MARS are $O(N)$ and $O(1)$, respectively. Since there are a limited number of MARSs controlled by the AMC, the time for computing the moving destinations can be neglected, comparing with the delay introduced by MARS movement. Additionally, in the above discussion, $MARS_i$ moves to just cover the MH. One can also enforce $MARS_i$ to move farther so that the distance between $MARS_i$ and the MH is shorter than $R$ (e.g., equals to $\delta R$, where $\delta \leq 1$ is a guard parameter). This may reduce the probability that a call accommodated by MARSs to be dropped, because of the “guard distance”. But at the same time, it also decreases the probability of the MARSs to finish a successful movement, and in turn results in a higher call blocking/dropping rate.

**Extended Approach**

In the basic strategy discussed above, the primary movement attempt fails if there are no intersection points between the D-circle and the line AB when $MARS_i$ is a seed (case 1), or between the D-circle and the S-circle centered at $MARS_{i-1}$ when $MARS_i$ is not a seed (case 2). In both cases, we can use the following extended approach. More specifically, if the circle centered at $MARS_i$ intersects the D-circle, then one neighbor MARS of $MARS_i$ can move to the intersect point, where it can cover the MH and keep connection with $MARS_i$ at the same time. Since moving the upstream node (i.e., $MARS_{i-1}$) may break its connection to the seed MARS, AMC will try to move the downstream node (i.e., $MARS_{i+1}$) and make it as a proxy. More specifically, AMC treats $MARS_{i-1}$ as “$MARS_i$” in the basic approach and proceed using the basic approach to compute the moving destination. Otherwise, if there is no intersection between the D-circle and the circle centered at $MARS_i$, it is impossible to move any of the downstream nodes of $MARS_i$ to cover the MH.

However, even if the above attempt is failed, the request can still be accommodated by moving the entire cluster. More specifically, AMC will compute the projection of the MARS cluster and the MH on the vertical axis (see Fig. 1 (d)). If the projection of the MARSs covers that of the MH, AMC will compute the moving direction, distance and time when the entire cluster of MARSs move as a single entity (without changing their relative positions) toward MH X while keeping the seed of this cluster on the cell border (i.e., still being a seed MARS). If the moving time is no longer than $t$, the cluster will move until at least one S-circle of MARSs intersects the D-circle (see Fig. 1 (d) for the cluster shifting approach). Then the basic approach can be applied. Of course, the MARSs still need to check if any of the on-going connections will be dropped or not.

2) Strategies For Secondary Movement: If primary movement is impossible, AMC will perform the secondary movement, whose objective is to move MARSs to facilitate secondary relaying. This can be accomplished by broadcasting a Location_Query message to all active MHs in the cell where MH X is located. Upon receiving the Location_Query message, the MHs respond with a Location_Query_Ack including their current location information to AMC. After AMC receives the locations of the MHs, it will find at least one pair of MH (which is an active MH using a cellular channel but not the MH requesting a relaying service) and MARS (e.g., $MARS_i$) with the shortest distance. Similar to the primary movement, AMC will compute the destinations of the related MARSs, and the MARSs will check to see if they can move or not based on the existing relaying connections. However, instead of primary relaying, a secondary relaying will be performed after a successful MARSs’ movement.

**III. Conclusion**

In this paper, we have introduced a novel concept called “managed mobility”, and addressed the mobility of the relaying devices called Mobile Ad hoc Relaying Stations (MARSs) in the integrated Cellular and Ad hoc Relaying (iCAR) system. We anticipate that the idea of managed mobility proposed in this paper for the iCAR system as well as the mobility management strategies may also be applied in other ad hoc networks, such as the self-reconfigurable sensor network, to reduce additional node deployment cost and increase fault tolerance.

**REFERENCES**