Cellular Ad-hoc Relay for Emergencies (CARE)

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***Abstract*— Emergency services are being improved by the Federal Communications Commission (FCC) by obligating wireless service providers to be E911 compliant by December 2005. We propose a system which is not only compliant with the E911 requirements but also provides enhanced functionality to relay an emergency call arising from a user outside the cellular coverage area via another user within the range of the network. Simulations based on the GSM wireless technology have been described and results show that Cellular Ad-hoc Relay for Emergencies (CARE) achieves a system efficiency of above 90%.**

Keywords: Relay; Cellular; E911.

I. INTRODUCTION

The FCC requires wireless service providers to upgrade the existing emergency relief services to be compliant with E911 specifications [1]. E911 is to be implemented in 2 phases. Phase I requires wireless service providers to forward wireless 911 calls to a Public Safety Answering Point (PSAP) containing information about the location of the cell tower through which the E911 call was processed and the 10 digit wireless phone number placing the call. In phase II of E911, wireless service providers are required by the FCC to have the ability to send the actual caller's location (for example, to within 410 ft. of accuracy, 67% of the time) to the E911 PSAP. While phase I is a service oriented provision and has already been implemented, phase II needs network assisted and handset assisted calculations for finding the location of the emergency request within a prescribed radius of accuracy and must be realized by December 2005. Such an implementation of emergency response requires connection to the wireless network. However, many situations of emergency arise at locations where either the service is absent or the signal is insufficient to support a call. Examples of such locations include basements, pits, valleys and fast fading terrains.

The proposed system, Cellular Ad-hoc Relay for Emergencies (CARE) relays voice calls arising from such locations that are void of cellular coverage, via users who have suitable mobile and channel characteristics, to the PSAP. CARE can also be used when signal strength from BTS is sufficient to place a call but the caller doesn't have enough battery energy to transmit up to the BTS. Instead, the caller communicates with another node in the vicinity that is closer than the BTS. We present synchronization, collision avoidance and relay selection strategies for the system.

The performance of the system is also evaluated based on the efficiency of synchronization and collision avoidance algorithms. In addition to the relay algorithm, we propose a method for Automatic Location Identification using CARE making it compliant with E911 Phase II requirements. Although the algorithms are proposed for a Global System for Mobile (GSM) [2] network, they can be extended to other types of cellular networks based on Code Division Multiple Access (CDMA) with relevant modifications.

The concept of cellular relay was initially proposed in [3] to enhance coverage area for delay insensitive traffic (data). Using centralized scheduling, [4] showed substantial throughput gains using cellular relays. In spite of such advantages in employing relays, limited battery power at the relaying nodes remains a major stumbling block for its widespread implementation in cellular systems. In [5], methods to mitigate the power consumed in the relay using routing intelligence and power control are proposed. However, with a federal mandate and relays restricted to emergency calls, relaying could be implemented in cellular networks to ensure enhanced E911 coverage.

CARE can be deployed in the existing wireless framework with minor changes in the mobile handsets and BTS. The primary change needed is use of frequency shifters in the handsets to facilitate transmission at downlink frequencies and receiving at uplink frequency. Current cell phones only transmit at uplink frequency and receive downlink frequency from the Base Transceiver Station (BTS) since the communication is always exclusively between the cell phone and the BTS. However, in a CARE system, call relay requires the Caller and CB to communicate with each other and hence needs the handsets to transmit at downlink and receive at uplink frequencies. Other minor changes required are software programming scripts that would help for recognition and processing of the CARE system packets both in the handset and the wireless network.

The rest of this paper is organized as follows. In Section II, system description of CARE detailing the process of establishing an emergency relay call is presented along with simulation results for the system efficiency. The ALI algorithm

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in CARE is described in Section III followed by conclusions in Section IV.

II. SYSTEM DESCRIPTION

The CARE system proposes extending the coverage for E911 calls by relaying emergency calls via users within the range of the wireless network. The main challenges in successful relay of an emergency call are:

A. Locating the Potential Call Bearers (PCBs)
B. Synchronizing with the CB
C. Collision avoidance for responses from the PCBs
D. Timeslot allocation and call setup

We now discuss the proposed scheme to overcome these challenges.

A. *Locating the Call Bearer*

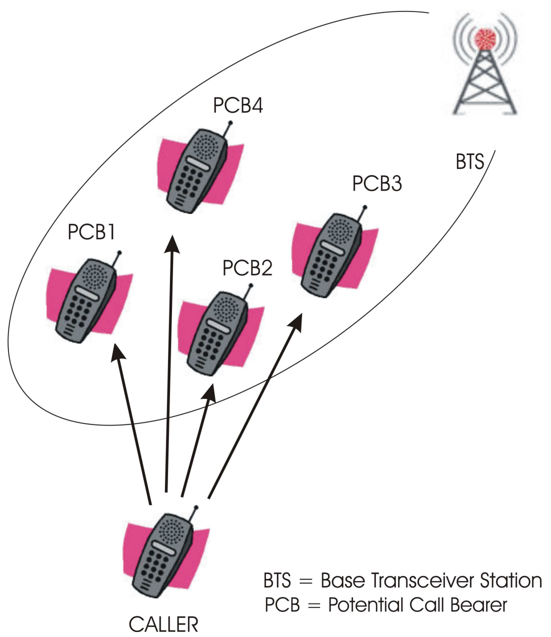

Figure 1. Wireless multicast for locating potential call bearers

CARE system gets activated whenever the user dials 911 or any emergency number, and the signal strength is insufficient to place a call. The primary task in the protocol is to locate a user having the channel and handset resources to relay this emergency call. To achieve this, the caller sends multiple packets denoted as INQUIRE packets in the air using a wireless multicast as shown in Fig. 1. The packets are disguised similar to the Control Channel (CCH) and contain the Caller's Phone number, International Mobile Equipment Identification (IMEI), timestamp, and the wait time for the CBs to start transmitting the ACK packet.

The INQUIRE packet can be detected by other handsets only if they receive this packet during the Radio Time Slot (RTS) 0. Hence, the packet has to time-synchronized with the signaling time slot (RTS0) of the BTS. Assuming that the RTS0 for all BTS in the network are exactly synchronized, successive INQUIRE packets are transmitted with a random back-off delay D between them. This is done to ensure that at least one packet is received within the tolerance interval Δ of the beginning of RTS 0 period. Here, $\Delta = 5\mu s$, the time window on each side of RTS 0, within which the INQUIRE packet must be received for it to be successfully detected. We show by simulations, that within 20ms of the transmission of the first INQUIRE packet, the probability of synchronization is almost 100%. The time for transmission of a INQUIRE packet is assumed to be very small compared to the back off window length D and is ignored. Fig. 2 shows that a large number of retransmissions (>1500) are required to ensure a success rate greater than 90%. Keeping in mind the criticality of the call, the back off window length D is set to $10\mu s$.

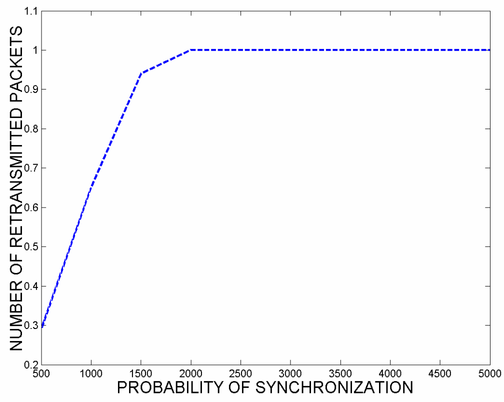

Figure 2. Probability of Synchronization with RTS 0 of the call bearer against the maximum number of retransmissions of the CARE packet

B. *The Acknowledgement (ACK) Packet*

Each of the mobiles that receive the INQUIRE packet initiates an internal script that fetches the following information from its own handset:

- Mobile Phone Number
- IMEI
- Battery Power Level
- Signal Strength Level
- On-call / Idle
- Clock count
- Available timeslots (if it is already on another call)
- Synchronization Information

An ACK packet is generated comprising this information as shown in Fig. 3. It has headers added for identification and processing by the CARE software module in addition to the fields of information. The ACK packet is sent after waiting for a predetermined time, as indicated in the INQUIRE packet. The Call Bearer sending this packet is identified by the Mobile

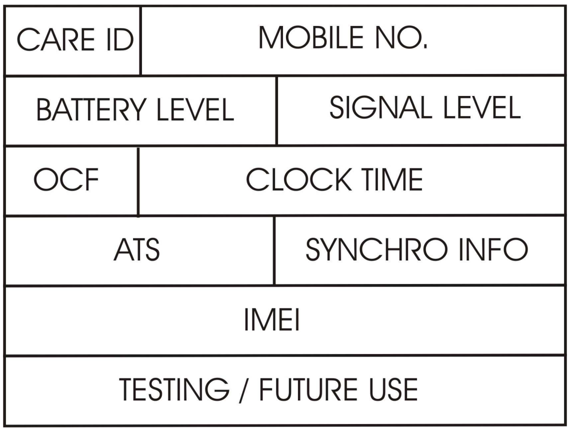

Figure 3. ACK Packet Fields

phone number and IMEI interpreted from the incoming packet. If the signal strength or battery level at the PCB is insufficient to support a relay call, an ACK packet is not generated and no reply is sent back to the caller. This will avoid any multi-relay situations that may occur otherwise.

The ACK packet has sufficient information to initiate a CARE session between the caller and the call bearer. The different fields of the packet are described below:

CARE ID – This is a number assigned by the potential call bearer's CARE module for identification purposes. Every response is assigned a unique CARE ID and used for identification purposes during retransmissions.

Battery Level – The information of the amount of battery power is fetched from the call bearer's phone and stored in this field. This helps in comparing various potential call bearers and the one who has the highest level would be most suitable to support the relay of the emergency call.

Signal Level – This information is regularly updated by the cell phones based on pages from the nearby base stations. It is placed in this field to decide whether a relay call can be supported.

OCF (On Call Flag) – The On-Call flag indicates to the caller whether or not the potential call bearer is currently on a call with the base station. It also informs the caller about the type of communication in which it is engaged by using:

0 = Idle
1 = Voice call in progress
2 = Data call in progress
3 = Not used (only 0, 1 or 2 are valid options)

ATS (Available Time Slots) – This field lets the caller know which time slots are available for initiating a CARE session. This information is crucial since the caller and CB have to select a time slot which will not be used by the CB to communicate with the base station.

Clock Time – The clock time field has the count of the clock in the call bearer's phone. This count is used to set the reference time for all future communication. It also has a timestamp of when the INQUIRE packet was received and when the ACK packet was sent to enable Round Trip Time (RTT) calculations at the Caller.

Synchronization information – This field is used to communicate timely synchronization information that is required for communication between the two mobile phones. It is critical information since the system has to be time efficient and emulate a normal voice call [2] adhering to the technicalities of the same. It is similar to the Sync information transmitted by the BTS in RTS 0.

IMEI – This is the International Mobile Equipment Identity number used as additional identification for the mobile phone.

Testing bits / Future use – These bits are reserved for future work and tackling handoff issues when the call bearer moves beyond the reach of the caller.

C. Collision Avoidance at the Caller

All PCBs are assumed to be connected to the same BTS and hence their RTS0 begin at the same time i.e., all PCBs are synchronized at the same time. Once synchronized, the PCB's wait for a predetermined time as set in the INQUIRE packet and send ACK packets. At the caller, there will be collisions due to ACK packets from multiple PCBs arriving at the same time. This problem is mitigated using a collision avoidance routine. The routine is a uniform back off algorithm, in which each PCB backs off for a random time W, where W~**U**(0, L) before sending the ACK packet. L is the back off window size. The caller then collects all the ACK packets received within T seconds commencing after the transmission of the final INQUIRE packet, which was set at 300μs for simulations. We assume here that the loss of an ACK packet is only due to collision and the ACK packets are not retransmitted. The success of such a collision avoidance mechanism depends on the number of PCBs in the vicinity. Fig. 4 shows that over a wide number of PCBs, the probability of receiving at least 3 collision free ACK packets is close to 1 (seen in the flat area of the curve). As the number of potential call bearers increase, more collisions occur, resulting in the reduced probability as seen for number of PCBs > 30 in Fig. 4.

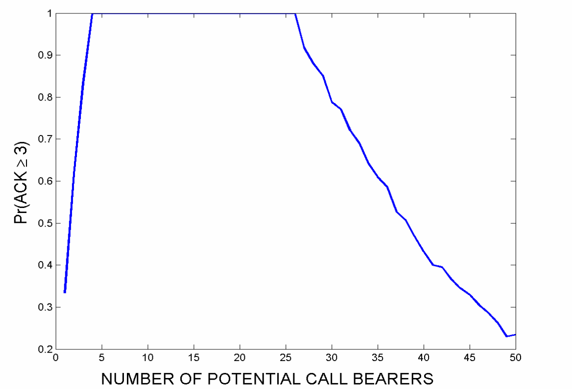

Figure 4. Probability of receiving atleast 3 collision free packets against the number of potential call bearers

D. Selecting the call bearer

After collecting the responses from the potential call bearers, a decision has to be made about selecting the call bearer. The caller calculates the RTT based on the information in clock count field from the ACK packet. The CARE module in the caller's cell phone then runs a script which compares the data received from the responses against each other to select the call bearer.

At the caller, the CB is selected based on four factors – Call status, signal strength, battery power, RTT. The exact function *f*(call status, signal strength, battery power, RTT) can be chosen heuristically. These factors are now explained in detail.

- Call Status – A cell phone already on a call utilizes a time slot and is also utilizing a lot of battery power. Also, if the potential call bearer is engaged in a data session like GPRS, still significant battery and channel resources are being utilized. To support another call would mean managing a total of 3 conversations: One that is already in progress, second with the caller and third with the base station that is relaying the conversation to and from the caller. Hence, this factor is given high importance when choosing the call bearer.

- Signal Strength – The value of the signal strength level can be used to decide whether a given call bearer is more or less likely to indulge in a handoff with the current base station. A high signal level generally implies that the user is less likely to switch cell sites. Hence the CB with highest signal level is chosen to avoid call transfer complications across the base stations.

- Highest battery power – A CARE session requires the CB to maintain 2 simultaneous voice conversations; one with the caller and the other with the base station. This activity would demand significant power from the mobile device. A termination in the CARE session due to insufficient battery power of the call bearer is highly undesirable. Hence the CB with highest battery power is selected.

- Lowest Round Trip Time – A call bearer with lowest RTT implies that the call bearer is closer to the caller compared to other responses. This implication also means that this user is less likely to move out of the range of the caller. In addition to that, lesser the RTT, lesser would be the power usage by the cellular devices in establishing and maintaining a communication dialogue.

E. Establishing a CARE session

Depending on the function to choose the best CB, a SELECT packet is sent during the next RTS0 to the selected CB. This triggers a call setup by the call bearer with the base station. At the same time, required synchronization messages are being sent back and forth between the caller and the call bearer. The information in the packet received from that user is further analyzed. The synchronization information is taken into account for setting the system clock and the reference time. These messages are not different from the way a normal call is setup.

The seven time slots are divided into 2 groups – Group 1 includes RTS 1 thru RTS 3 and Group 2 has RTS 4 thru RTS 7. The CB, depending upon the time slot allocation by the BTS, conveys information to the caller. If the BTS allots a time slot in group 1, the CARE session is established at RTS 4; if the BTS allocates a time slot in group 2, the CARE session selects RTS 1 for communication. The caller wakes up at RTS 1 and RTS 4 for CARE communication. If it doesn't see any communication on RTS 1, it sets RTS 4 for the CARE session and vice versa. The CARE session selects either timeslot 1 or 4, depending on which is available. This scheme requires the cell phone to wake up from sleep mode only during RTS 1 and RTS 4, instead of searching for information in all time slots, thus saving system resources.

The bits received from the caller are placed in a buffer at the CB and relayed onto the base station and vice versa. However, the selection of time slots is dependent on the call bearer and the caller sets up the buffer to transmit and receive voice bits according to the call bearer's allotment. Thus a full duplex voice communication link is established between the emergency caller and the BTS. The entire call is summarized in the signal flow diagram shown in Fig. 5.

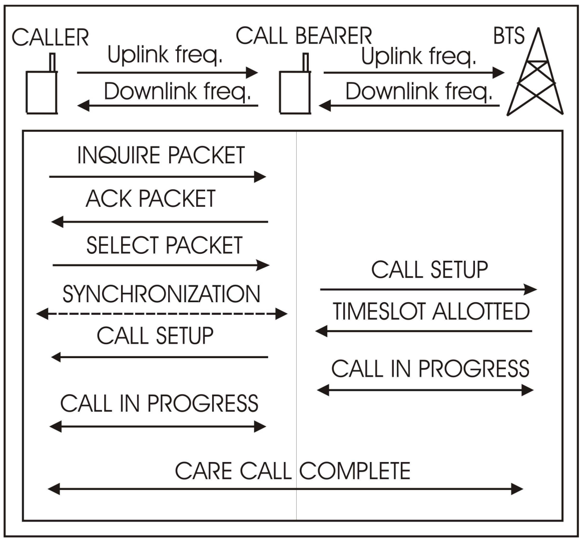

Figure 5. Signal Flow

F. System Efficiency

The success of the CARE system is determined by the ability to synchronize with the RTS0 and the reliability of the collision avoidance mechanism. The synchronization routine does not know the number of PCBs around it and its success depends only on the number of retransmissions of the INQUIRE packet. The back off times for collision avoidance for each of the PCBs begin at the same time and depend only on the number of PCBs in the vicinity. Since factors affecting the success of the above two processes are independent, their success probabilities are independent. The system efficiency which represents the probability of establishing a successful CARE call is defined as the product of the probability of synchronization at the PCBs and the probability of receiving at least 3 collision free responses at the caller and is plotted in Fig. 6. It can be observed that Fig. 6 is similar to Fig. 4, except for the scaling in the ordinate axis by an amount equal to the probability of synchronization for a given number of retransmissions (Fig. 2). It can be seen that increasing the number of retransmissions, increases the efficiency of the system.

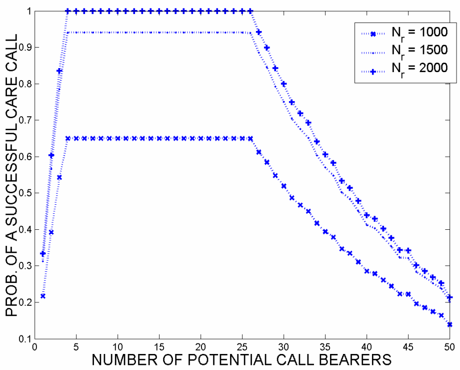

Figure 6. Success ratios of a CARE call against the number of potential call bearers. N_r is the maximum number of retransmissions of the CARE packet.

III. Locating an Emergency

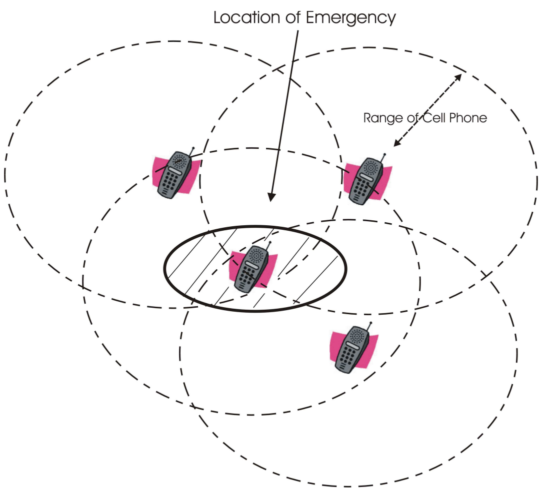

Figure 7. Automatic Location Identification

In addition to the call relay, CARE can be integrated with a network and handset based location mechanism to provide Automatic Location Identification (ALI). This is achieved by further analysis of the INQUIRE packets received by potential call bearers.

When the INQUIRE packet is sent by the Caller to CBs, the CBs receive the packet when it hits them at RTS 0. These CBs send information to their BTS about an emergency request. The range of a cell phone depends on its battery power and can be generally assumed to be equal. Taking this range into consideration, the location of emergency is calculated by triangulation of the common region of individual ranges of the phones. The higher the number of BTSs they are attached to higher is the accuracy of the location of emergency. The wireless backhaul consisting of the BSC and MSC have knowledge of the location and coverage of a BTS, which further assists emergency location information. This aspect of the CARE system has to be further investigated in future work to achieve the accuracy specified by the FCC E911 specifications [1].

IV. Conclusion

In spite of constant increase in the number of cell sites being commissioned, it is practically impossible to provide coverage to all user accessible places. Degraded signal quality would always exist in some areas due to terrain, fading and inferior equipment. CARE can play a crucial part by facilitating emergency relief in such cases. Not only is CARE compliant with the E911 requirements, but also a step further since it facilitates access to Public Safety Answering Points (PSAP) to users who cannot reach the network directly. Further research on Automatic Location Identification and handoffs from one CB to another will make CARE a choice for future emergency solutions.

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