A Hybrid Communication Protocol For Cellular Architecture Using Energy-Efficient AODV

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Abstract - Cellular mobile communication nowadays is one of the fastest growing means of communication. With the load on the channel between base stations and mobile hosts increasing, there is an increasing demand on the communication means to be energy efficient. Some of the algorithms like AODV have already come up in the mobile adhoc networks to counter the problems of excessive energy consumption. In this paper we have proposed a new energy efficient routing scheme for communication in cellular networks that uses the idea of AODV and the existing communication scheme used in cellular networks. The proposed work also offers efficient handling of packet loss during handoff.

Keywords: Cellular architecture, Global System for Mobile Communications, Ad-Hoc On-Demand Distance Vector Routing Protocol (AODV).

1. Introduction

A multihop cellular network is the basic idea of our proposed scheme and it adopts the multihop nature of the wireless adhoc network [2] to enable the overall system capacity to be more efficient by reducing the total transmitted power [1]. Here energy efficient routing is the important issue because the cellular network consists of battery-powered mobile hosts. Cellular architecture uses the principle of frequency reuse [3] to efficiently serve the customers. Low powered mobile hosts and radio equipment at each cell site permit the same radio frequencies to be reused, thus multiplying calling capacity without creating interference.

Global System for Mobile Communication is the most widely used current technology for mobile telephony and data communication. Abbreviated as GSM, these systems were originally conceived for voice telephony and provide only very limited bandwidth for data communication [3]. In this architecture, there is a base station that is a level higher to that of all the mobile hosts within a range covered. It periodically takes note of the number of mobile hosts in a network and is kept informed of all other basic features of the mobile hosts. Once a mobile host needs to communicate with another mobile host, then this mobile host will request for a communication link to its parent station, i.e., the base station. The base station then forwards it to the base station that controls the destination mobile host or directly to the mobile host if the destination is in its range.

In this paper, we use the multihop routing techniques of the adhoc networks in Cellular communication for the following reasons:

- There is an excessive workload on the base stations to carry out these above mentioned functions. For example, a destination mobile host may be the immediate neighbor of the current host and still the source may contact the base station for communication in the GSM architecture. With the growing number of multimedia applications and the multimedia information propagation being incorporated into the cellular networks, this may bring down the performance to a large extent.
- In big cities, there may be many distractions while mobile hosts need to communicate with the base station. There may also be a lot of mobile hosts contending for simultaneous communication and this may cause a traffic jam and hence a delay in transmissions may result. In such a situation, one can adopt the multihop routing nature of adhoc networks.

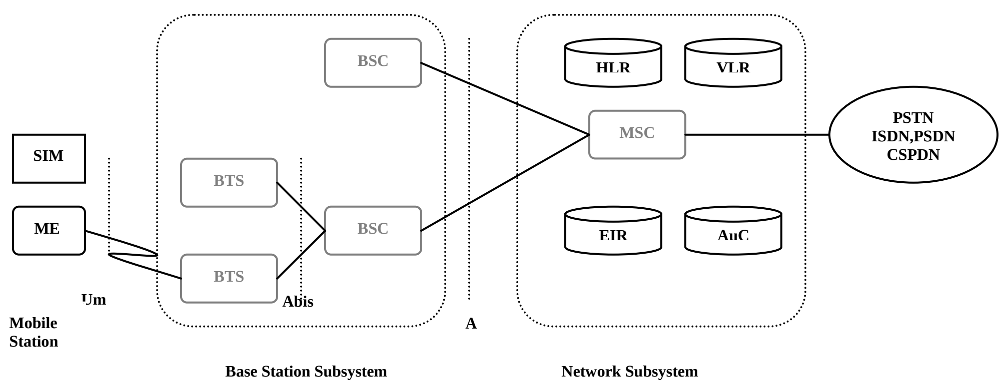
Recently a interesting work [1] has been reported that tries to reduce the excessive load on base stations caused mainly due to many simultaneous communications among the different mobile hosts. This work [1] considers the avoidance of usage of base stations as much as possible when different mobile hosts want to communicate. For this purpose the authors have used the well established AODV [4] which is usually used for mobile Ad-Hoc communications. They have considered the power consumption for determining the best (minimal) path for a source-destination communication. To determine a best path they have used a measure of the cost associated with any path following the idea reported in [8]. Even though this is a very novel approach it has some important short comings.

The first shortcoming is: movement of the mobile hosts (they may belong to different cells) may cause the route discovery using AODV much complex resulting in inefficient utilization of bandwidth and delay in data delivery. The second shortcoming is: the packet loss due to movement of mobile hosts (during handoff [7]) has not been addressed. In this work we have modified the idea of the above work [1] from the view point of limited use of AODV. We have presented a hybrid approach which comprises of limited use of AODV and the existing communication scheme used in GSM architecture (from now on let us call it GSM-CS). We achieve faster delivery, better band width utilization and perfect handling (no packet loss) of handoff situations, while ensuring reduced load on base stations.

This paper is organized as follows. In Section 2, we have given a brief but clear idea about GSM architecture and how communication takes place in it. We also state briefly how AODV works. In Section 3, we have stated the problem considered in this work. Section 4 contains the proposed protocol along with an illustration. Section 5 draws the conclusion.

2. Related Ideas

Since in our work we consider a limited application of AODV in cellular networks, it is appropriate to briefly state the way communication takes place in cellular networks as well as in AODV. The architecture of Global system for Mobile Communication is divided into three broad parts [3]. The Mobile Host is carried by the subscriber. The Base Station Subsystem controls the radio link with the Mobile Host. The Network Subsystem, the main part of which is the Mobile services Switching Center (MSC), performs the switching of calls between the mobile users, and between mobile and fixed network users. Fig. 1 shows the layout of a generic GSM network. The MSC also handles the mobility management operations. The Mobile host and the Base Station Subsystem communicate across the Um interface, also known as the air interface or radio link. The Base Station Subsystem communicates with the Mobile services Switching Center across the A interface as shown in the Fig. 1



SIM Subscriber Identity Module
ME Mobile Equipment
BTS Base Transceiver Station
BSC Base Station Controller
HLR Home Location Register
VLR Visitor Location Register
MSC Mobile Services Switching Center
EIR Equipment Identity Register
AuC Authentication Center

Fig. 1 General architecture of a GSM network

The Base Station Subsystem is composed of two parts, the Base Transceiver Station (BTS) and the Base Station Controller (BSC). These communicate across the standardized A_{bis} interface, allowing (as in the rest of the system) operation between components made by different suppliers.

The Base Transceiver Station, also called as a Base station (BS), houses the radio transceivers that define a cell and handles the radio-link protocols with the Mobile Host. A cell is defined as the basic geographical unit of a cellular communications system. Fig. 2 shows the basic GSM cell structure where each hexagon (C_i, C_j, and C_k) represents a cell and each of these three cells is split in to three sectors, maintained by the base stations. The cell site equipment provides each sector with its own set of channels. The cell site transmits and receives on three different sets of channels, one for each part or sector of the three cells it covers. In Fig. 2 cell C_i has three base stations (BTS)

X,Y and Z and the shaded portion represents the area covered under the base station X (it will cover one sector in each of the cells C_i , C_j, and C_k).The Base Station Controller manages the radio resources for one or more BTS's. It handles radio-channel setup, frequency hopping, and handovers, as described below. The BSC is the connection between the mobile host and the Mobile Switching Center (MSC).

In the GSM architecture, if a mobile host desires to communicate with any other mobile host, it contacts the nearest base station (a BTS as in Fig. 1) and this BTS will check for the present location of the destination mobile host with BSC of that cell. If the destination host is with in the same BTS the data is directed to the mobile host. If destination host is present within the same BSC then the data packet reaches the destination host via BTS and BSC. Similarly data goes to one more level (i.e. MSC) if destination host is not present within the same BSC. If destination host is not found within the same MSC it is routed through the PSDN (public switched telephone network) to different MSC's and to their respective BSC to BTS to destination host. Thus the connection is established between a source mobile and destination mobile. In this work, we further call this communication mechanism in GSM architecture as GSM Communication Scheme (further abbreviated as GSM-CS). Below we briefly state how AODV works.

The Ad-hoc routing protocols can be classified in to On-Demand and proactive [1]. It is shown that in [6] On-Demand routing protocols are better than proactive routing protocols. Ad-Hoc On Demand Distance Vector (AODV) [4] routing protocol builds routes using a route request / route reply query cycle. When a source node desires a route to a destination for which it does not already have a route, it broadcasts a route request (RREQ) packet across the network. Nodes receiving this packet update their information for the source node and set up backward pointers to the source node in the routing table.

In addition to the source node's IP address, current sequence number, and broadcast ID, the RREQ also contains the most recent sequence number for the destination of which the source node is aware. A node receiving the RREQ may send a route reply (RREP) if it is either the destination or if it has a route to the destination with corresponding sequence number greater than or equal to that contained in the RREQ. If this is the case, it unicasts a RREP back to the source. Otherwise, it rebroadcasts the RREQ. Nodes keep track of the RREQ's source IP address and broadcast ID. If they receive a RREQ which they have already processed, they discard the RREQ and do not forward it. As the RREP propagates back to the source, the nodes set up forward pointers to the destination. Once the source node receives the RREP, it may begin to forward data packets to the destination. If the source later receives a RREP containing a larger sequence number or contains the same sequence number with a smaller hopcount it may update its routing information for that destination and begin using the better route.

Since AODV has a low packet overhead and the fast expiration of unused routes, it is used most frequently in the Mobile Adhoc Networks. AODV can be extended into cellular networks with some modifications in the packet structure and thereby making it energy-efficient. In the cellular network, the mobile host can be considered as a node in the mobile adhoc networks.

3. Problem Formulation

Since our present work is a modification of the idea used in [1], so we start with a brief description of their work. In [1], On Demand Energy-Efficient routing using AODV utilizes the multihop nature of the mobile hosts in a cellular network. Here, the source host that intends to communicate broadcasts a RREQ (Route Request) packet to the neighbors. The intermediate hosts rebroadcast this request until it reaches the destination. When the destination host receives this RREQ packet, it unicasts a Route reply (RREP) packet to the source host to establish a path. In this scheme, the data structures used have explicit fields in the packet that indicate the Source and the cost accumulated through each path to the destination. This is considered as an energy- efficient routing protocol similar to MTPR (Minimum Transmission Power Routing) [8] which is regarded as the energy- efficient routing protocol. The packet format used in this method [1] is as follows:

<Type, Source IP Address, RREQ id, Destination IP address, Accumulated cost, H_{max}, Hop count>

Most of the fields have the names that are self-explanatory. Type is used to distinguish between RREQ and RREP. RREQ ID is incremented whenever a source host sends a new RREQ. When a destination host is a base station, Destination IP address of a RREQ packet should be a predefined value that is not used for mobile hosts and represents a set of base stations. Accumulated cost means the accumulated path loss through the source host to the RREQ sender. H_{max} is maximum allowable number of hops and determined by a source host and is basically a delay constraint which is directly proportional to the number of hops. We explain in detail about the calculation of accumulated cost below because we use the same method to find out the best path in our approach. HopCount is the total number of hosts traversed thus far, leading up to the current mobile host.

In Fig. 3, S denotes the source host and D denotes the destination host and a, b, c, d, e and f are the intermediate hosts. S broadcasts a RREQ packet to search for a path to a host D, and hosts a, and b receive it simultaneously.

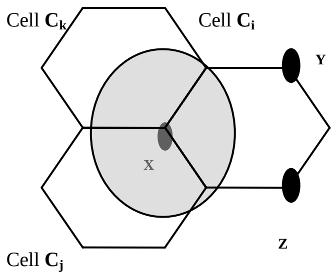


Fig. 2 Structure of GSM cell

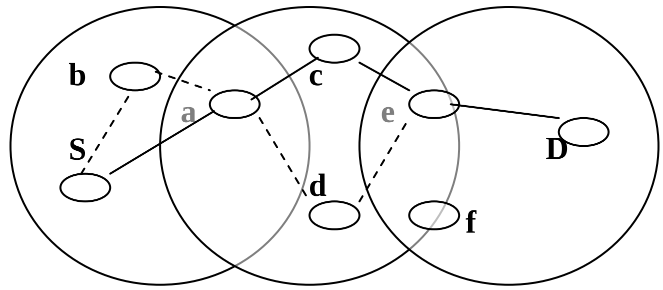


Fig. 3 Path creation between a source host and a destination host

The intermediate hosts process the RREQ packet with the same source IP address and the RREQ ID. Hence the multiple reverse paths (RREP) to a single source host were allowed in this routing scheme. The last 2 fields of the packet information avoid the controversies due to multiple route formation. Each intermediate host maintains the minimum hop count values and Accumulated cost values of the RREQs that it receives. If these values of the currently received RREQ are larger than their stored values, the RREQ is rejected. This helps in avoiding the paths from making the loops around the same host. The destination host 'D' waits for a time of (H_{max} - Hop count) and selects the least cost path received during this period. Then the destination host will send a RREP packet back to the source through that path and hence a communication link is established.

An intermediate node that received a RREQ packet checks the HopCount in the packet, increments by one and compares it with the H_{max}. If they are same the packet is discarded, otherwise the accumulated cost field will be updated using the following formula.

Accumulated cost = Accumulated cost + cost of link between the RREQ sender and receiver

It is assumed that each host knows the cost of link to the neighbor host by measuring received power level[5]. The received power $P_{received}$ is expressed by

$$P_{received} = P_{max} (C_1 / d)^n C_2$$

Where C_1 , C_2 and n are the constants which are related to system parameters and physical environment. P_{max} is the maximum transmission power level. Here we assume that $C_1 = C_2 = 1$ and $n = 4$ for simplicity. The distance d between request sender and receiver can be calculated by the hosts. Hence, $P_{transmitting}$, at which the request sender will transmit data packets, is calculated by

$$P_{transmitting} = d^4 . P_{req}$$

Where P_{req} , is the maximum decodable power level. $P_{transmitting}$, is the link cost between the RREQ sender and the receiver.

The above mentioned approach [1] tries to reduce the excessive load on the base stations by introducing the power efficient multi-hop communication in cellular architecture. They have considered the power consumption at every node to find out the best path between the source and destination. However this approach [1] has not taken into account the location of the mobile hosts (source and destination may be in different cells), and also the packet loss caused by the mobility of the mobile hosts (i.e. during handoff [7]).

In this proposed work we have modified the idea of the above work [1] by using the existing GSM-CS along with AODV. This work comprises of limited usage of AODV and the existing communication scheme used in GSM architecture (GSM-CS). Faster delivery, better band width utilization, and perfect handling of packet loss during handoff [7] are achieved in our work, while ensuring reduced load on base stations.

4. The Proposed Approach

In our approach, AODV is used by the Mobile host to transmit the data to other mobile host only if both of their present locations are in the same cell otherwise we will follow GSM-CS. There by we limit the usage of AODV. We also propose an approach to damp the propagation of the packet (it can be a request or a data packet) using AODV if destination host is not present in the same cell as the source. This is illustrated with an example in the next section.

The need of multihop communication if both the source and destination mobile hosts are present in the same cell is explained below. As shown in Fig. 4 mobile host S is trying to communicate with the mobile host D which is in the same cell. According to GSM-CS for the communication, S will contact the base station X which in turn will contact base station Z and then to D. But we see that even though these mobile hosts are in the same cell, they are still consuming the services of the base stations which can be huge when large numbers of mobile hosts are present in a cell. We propose the use of AODV for the communication between S and D since they are present in the same cell.

4.1 An illustration

We describe our approach using the example as shown in Fig. 5. There are three cells C_i, C_j, C_k and C_l respectively and four base stations X,Y,Z, and Z' respectively. Here all the mobile hosts present in cell C_i will communicate with other mobile hosts residing in other cells world using the base stations X,Y, and Z [3] (using GSM-CS). The shaded regions in Fig. 5 represent the area (belonging to cells C_i,C_k,C_l) covered by base station X, and let us consider one sector of X where cell C_i uses its services.

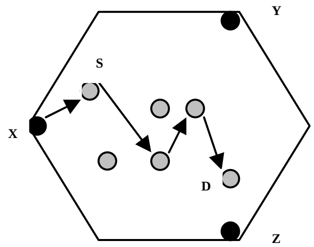


Fig. 4 Structure of a cell

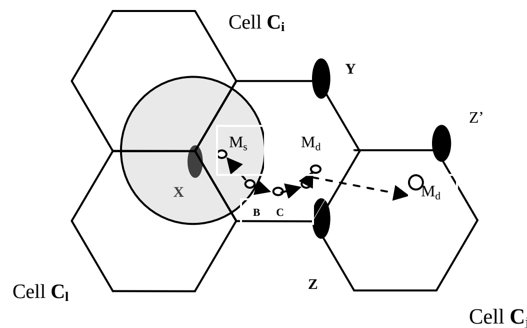


Fig. 5 Multihop communication within a cell

Consider a mobile host M_s, a source which wants to contact another mobile host M_d. Now, mobile host M_d, which is the destination, can be present in three scenarios and they are.

Case 1: M_d is present in the same cell as M_s.

Case 2: M_d is in some other cell C_k.

Case 3: M_d moves after the path has been setup and some information has already reached the destination.

How these cases are dealt with is further explained in this section.

Source M_s will be in the range of base station X, and if it wants to communicate with any other mobile host it will first send out a control packet to base station X. The packet is defined as follows.

<SourceID, DestID, aodv_flag>

This packet is referred to as P_{Bs} in our future discussions; aodv_flag is a Boolean flag that will be set to 1, if the source M_s wants to follow the AODV routing protocol for communicating with the destination M_d. Base station X will know the location of destination host M_d with the help of underlying GSM communication scheme (GSM-CS).

Soon after sending the packet to the base station X, source M_s will broadcast a route request packet P_{AODV} to all its neighbors. This P_{AODV} has the following parameters.

<Packet type, SourceID, RReqID, DestID, CellDiameter, HopCount, Cost>

Packet type is the field to differentiate between the Request and Reply. For convenience we further represent the reply packet as $P_{AODVrep}$. SourceID is used to identify the source. RReqID is the route request sequence no sent out by that source. DestID is the identification of the destination. In the worst case CellDiameter is the maximum number of mobile hosts present in the cell at that instant (if every mobile host in the cell are in between source and destination and they form a straight line) and this information is periodically updated by the base stations. HopCount is updated at each intermediate mobile host and is compared with the CellDiameter (D); if it is greater than the diameter it will discard the packet. Cost is the accumulated cost which is explained in [1]. Apart from that every base station will also have a control packet called damp_AODV which has a SourceID and damp_AODV flag set to one to stop the propagation of this P_{AODV} if needed.

Case 1: Destination and source are present in the same cell. This can be explained using the Fig. 5 where M_s is the source mobile, and M_d is the destination host. M_s will send the packet P_{Bs} to base station X and then P_{AODV} to all its neighbors, thus trying to establish a route to the destination. As the base station X knows that destination mobile M_d is in the same cell with the help of GSM communication scheme it doesn't do anything allowing the P_{AODV} to propagate further. During this route setup every intermediate mobile host will calculate the accumulated cost using the power function [1], and every mobile host accumulates its power value when it further propagates the P_{AODV} packet. In this scenario the packet propagates further hop by hop until it reaches the destination using the AODV principle. After the destination receives the packet, it will select one path with minimum cost. This reverse path set up follows the On Demand energy efficient routing [1]. The maximum number of hops that the source M_s waits for is the hop count which is equal to the CellDiameter (D). In the worst case D = number of mobile hosts present in the cell - 1. In this case the source M_s will wait for a maximum time of 2D units.

Case 2: Destination host M_d is out of the cell where M_s is located. In single hop, the source M_s will send the packet to the base station X and X knows the location of M_d is in some other cell. Meanwhile source M_s will broadcast P_{AODV} to its neighbors. Now base station X will send out damp_AODV control packet to all the mobile hosts within its vicinity to stop the propagation of P_{AODV} packet any further; thus saving the energy of the mobile hosts. And then base station X will follow the GSM-CS.

Case 3: In this case both the source and the destination hosts M_s and M_d are in the same cell. M_s will receive $P_{AODVrep}$ from the destination M_d setting up the path. Now destination M_d moves from its current location to another cell $\mathbf{C_j}$, i.e. handoff occurs. In Fig. 5 we have shown that M_d moved to the vicinity of base station Z'. As soon as the mobile host M_d registers itself with the base station Z', it will send out a control packet to Z' named as P_{Des}. This packet consists of three fields.

<SourceID, Data #, aodv_flag>

SourceID is the source M_s which is sending data to M_d using AODV, Data # will specify the number of the last data packet the destination M_d has received from M_s. This field is set to zero if just the link has been set up and there has been no data propagation. aodv_flag is set to 2 specifying that M_d is communicating with M_s using multihop. Then the base station Z' using the GSM-CS will forward that control packet to the base station X. X will send the packet to the source M_s and thus the source M_s stops sending further packets in the path set by the AODV and communicates with the base station X following the GSM-CS. Now M_s starts sending the data packets starting from K+1 to the base station X. This communication is carried on using the basic GSM communication scheme.

4.2 The proposed protocol

In this approach, we assume that Ms(i) is the source host, present in cell C_i and the nearest base station is B_x (i.e. it is in the range of B_x). The destination host is M_d(i), present in cell C_i. If the destination mobile host moves on to another cell say C_j then we represent it as M_d(j). The responsibilities of a base station, source host and destination host are stated below.

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This source procedure will be the same for all the three cases
At the Source host Ms(i)
    Step 1:  Set the HopCount equal to the CellDiameter.
    Step 2:  Set AODV_flag = 1 in the packet PBs        //packet to be transmitted to nearest Base station.
    Step 3:  Source Ms(i) send the packet PBs to the Base station nearest to it.   // to base station Ci(Bx)
    Step 4:  Ms(i) will propagate the packet PAODV to its neighbors.
    Step 5: Wait(event)                                 // event 1: arrival of damp_AODV control signal.
                                                        // event 2: arrival of PAODVrep packet.
                                                        // event 3: arrival of PDes Packet.
        On event 1:
            Ms(i) will start sending data through Ci(Bx)      //destination Md not in cell Ci
        On event 2:
            Setpath = Path received in PAODVack
            Send data to Md(i)                  //along the path in Setpath till end of Data
        On event 3:
            Stop sending data to Md(i)          //   Md moved from cell Ci to another cell
            K = Data#                           // Last packet received by Md before it moved from cell Ci
            Start sending data from (K+1)th packet to Ci(Bx) // Ci(Bx) will propagate data by GSM-CS

At the other Mobile Hosts
        If packet_recieved = PAODV
                If MobileHostID is Md(i)
                    Select best Path            // Using the power constraints selects the best path
                    Unicast   PAODVack back to source   // along the path selected.  Else If  HopCount not zero
                    Broadcast PAODV to its neighbors
                    Decrement HopCount
                Else If HopCount is zero
                    Drop the PAODV packet
        Else If packet_recieved = PAODVack
                Unicast  PAODVack to next host       //along the path set in the packet
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                    Else If packet_recieved = damp_AODV
                                    If SourceID in damp_AODV = SourceID in P_AODV  //Checking for Source Identification
                                          Drop the P_AODV  Packet.
                                    Else Continue propagation.

At the destination Host                    // In the event if the destination moves from one cell C_i to other cell C_j it will register
                                              itself to C_j(B_z')
             Step1: Data# :=  Last data packet received from M_s(i)
             Step2: Send P_Des to C_j(B_z')

At the Base station                                      // Now at the base station we have three routines.
          // The destination mobile host M_d(i) is present in the cell C_i(B_x) as M_s(i)
               Step1: Receive P_AODV from  M_s(i)
               Step2: If (AODV_flag = 1)                    // C_i(B_x) will know the location of M_d(i) by GSM-CS
                                  Doesn't do anything
                         Else follow GSM-CS

          // The destination host M_d is not in the same cell as M_s(i).
                Step1: Receive P_AODV from  M_s(i)
                Step2: If (AODV_flag = 1)                // C_i(B_x) will know the location of M_d by GSM-CS
                                 send damp_AODV         //set SourceID = M_s(i)
                                 wait (Data_packet)       // Waits for M_s(i) to send data packets
                                  follow GSM-CS           // M_s(i) will follow GSM-CS

          // The destination host M_d(i) is in the same cell as M_s(i), but after the data propagation starts, it moves to another cell C_j.

             Step 1: Receive the packet P_Bs from M_d via C_j(B_z')        // This will be at base station C_i(B_x)
                                                                  // M_d has received up to K packets before moving out of C_i
             Step 2: Send the information to M_s(i)
             Step 3: wait (Data_packet)       // Waits for M_s(i)  to send data packets from (K+1)^th and onward
                                  follow GSM-CS           // M_s(i)  will follow GSM-CS
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5. Conclusion

In this paper, we have proposed an energy-efficient multihop routing protocol for cellular network by using both the existing communication scheme used in GSM architecture and the AODV routing protocol. This proposed scheme reduces the load on the base stations and at the same time guarantees the successful communication between any pair of mobile hosts without much delay. In our approach, once a base station knows that a particular mobile host is not present in its cell, it immediately takes appropriate action to stop the multihop path discovery process; thereby conserving the mobile hosts' energy as well as the bandwidth. Besides, the proposed protocol solves the problem of possible packet loss due to hand off.

6. References

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