Energy-Aware Routing for Virtual Base Station On-demand Routing Protocol

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Abstract - Cluster-based protocols establish a dynamic wireless mobile infrastructure to mimic the operation of the fixed infrastructure in cellular networks. A Clusterhead or Virtual Base Station (VBS) is elected from a set of nominees to act as a temporary base station within its zone. In this paper, we derive a mathematical model describing the Virtual Base Station On-demand (VBS-O) routing protocol and then we study some issues regarding choosing gateways or Boarder Mobile Terminals (BMTs).

KEY WORDS: Wireless Mobile Ad-hoc, Medium Access Control, Routing, Quality of service.

I. INTRODUCTION

A wireless mobile ad hoc, or a multi-hop, network is a collection of wireless mobile hosts forming nodes that are arbitrarily and randomly changing their locations. No wired base station or infrastructure is supported, and each host communicates via radio packets. In ad hoc networks, each host must act as router, since routes are mostly multi-hop, due to the limited propagation range (250 meters in an open field). Due to the continuous movement of the nodes, the backbone of the network is continuously reconstructed. QoS communications in wireless mobile ad hoc network is highly dependent on routing protocols and medium access control (MAC) protocols. Routing protocols are responsible for maintaining and reconstructing the routes in timely basis as well as establishing the routes. Utilizing control packets efficiently reduces the control overhead, which makes the routing protocol efficient in bandwidth and energy consumption. Unlike On-demand protocols [1-3], communication in clustering protocols is mostly between clusterheads and BMTs, rather than flooding the entire network. BMTs are nodes that lie within the transmission range of more than one clusterhead. A clusterhead is elected and will be responsible for routing messages between nodes. Gateways are used to maintain communication between two or more clusterheads. Clusterheads and gateways form the virtual backbone of the network. A Clusterhead VBS is elected from a set of nominees, based on an agreed upon rule (the most connective node, the lowest ID, the highest energy level …etc) to act as a temporary base station within its zone or autonomous system. In the Virtual Base Station On-demand (VBS-O) routing protocol [4, 5], which can built on top of any infrastructure creation protocol, Warning Energy Aware Clusterhead (WEAC) infrastructure creation protocol [6] in this paper, mobile terminals elected as VBSs are used to track other mobile stations in the ad hoc network. In this paper, we introduce a mathematical model to study energy aware issues on VBS-O routing protocol. We then compare the mathematical results with simulation experiments.

II. Warning Energy Aware Clusterhead (WEAC) Infrastructure Creation Protocol

In the WEAC protocol [6], some of the MTs, based on an agreed-upon policy, are elected to be in charge of all the MTs within their transmission ranges, or a subset of them. This can be achieved by electing one to be a clusterhead. Every MT acknowledges its location via *hello* packets, sometimes called beacon packets. The method of electing a clusterhead from a set of nominees is based on its EL (as it will be shown later). Another issue to be addressed is the handing of responsibilities of a clusterhead over from one clusterhead to another. MTs are classified as follows:

a) Clusterhead: as it is named, the leader of the cluster.
b) Zone_MT: an MT supervised by a clusterhead.
c) Free_MT: an that is MT: not a clusterhead nor zone_MT. (i.e. it is not associated with a cluster).
d) Gateway or Border Mobile Terminal: MT that lies between more than clusterhead or Free_MT, it can be a clusterhead or a zone_MT or a free_MT.

Every MT has a *myCH* variable. An MTs myCH variable is set to the ID number of its clusterhead; however, if that MT itself is a clusterhead, then the myCH variable will be set to 0, otherwise it will be set to –1, indicating that it is a clusterhead of itself or a free node. A clusterhead collects complete information about all other clusterhead and their lists of MTs and broadcasts this information in its periodic hello messages. Zone-MTs, accumulate information about the network from their neighbors between hello messages, and they broadcast their neighbor_list to their neighbors in their hello packets. MTs announce their ID number with their periodic hello message. An MT sends a *merge-request message* to another MT if the latter has a higher EL and it should be more than or equal to THRESHOLD_1, (it will be explained later). The receiver of the merge-request message responds with accept-merge message sets its myCH variable to zero. When an MT receives the accept-merge message it and sets its myCH variable to the ID number of its clusterhead. The EL of each and every MT is characterized into one of the following four categories, Fig. 1:

1. MT EL ≥ THRESHOLD_1:

An MT is eligible to be a clusterhead and willing to accept other MTs to be under its supervision if these MTs have a lower EL. If the MTs with the same EL, which it is almost impossible, then the one with more number of neighbors wins. If myCH ≥ 0, no merge request will be sent by MTs, however, if myCH = -1, it will send a merge request to an MT with higher EL.

2. THESHOLD_1 < MT EL ≥THRESHOLD_2:

An MT will ignore any merge request messages that are sent to it by other MTs. If the MT is serving as a clusterhead, it will remain a clusterhead, but it will add no more nodes under its supervision, however; as in the first point, If myCH ≥ 0, no merge request will be sent by MTs. If the myCH = -1, then it sends a merge request message to an MT whose EL is greater than or equal to THRESHOLD_1.

3. THESHOLD_2 ≤ MT EL ≥ THRESHOLD_3:

If an MT is serving as a clusterhead, it sends a warning message to all MTs under its supervision, informing them to look for another clusterhead, nonetheless, they can remain with it till its EL drains to THRESHOLD_3. If the myCH = -1, then it sends a merge request message to an MT whose EL is greater than or equal to THRESHOLD_1.

4. MT EL ≤ THRESHOLD_3:

An MT will ignore any merge request messages and will send iAmNoLongerYourCH message to all the nodes under its supervision, if it was serving other nodes. If the myCH = -1, then it sends a merge request message to an MT whose EL is greater than or equal to THRESHOLD_1.

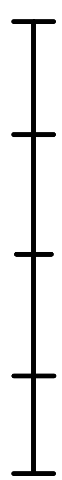

Fig. 1: Four power levels of each MT

III. Virtual Base Station On-demand routing protocol

In this section we introduce the Virtual Base Station On-demand routing protocol [4-5], which runs on top of the WEAC protocol. As it is named, there are some on-demand features added to the VBS-O routing protocol. Each Virtual Base Station (VBS) or clusterhead is in charge of a set of nodes in its neighbor. Only VBSs and free_MTs are eligible to acquire knowledge of the full network topology. Therefore, VBSs, BMSs and free_MTs construct the virtual backbone of the network. In the VBS-O routing protocol, we make use of the periodic updates, hello messages, which are broadcasted by each MT in the network. Since neighboring nodes, which are one hop away from each other, can hear each other, we suggest that neighboring nodes can communicate with each other without the aid of their VBS(s). Additionally, the new technique of broadcasting the neighbor list, used by the WEAC protocol, speeds up even more packet delivery and improves the throughput. If an MT wishes to send a packet, first it looks into its neighbor_list, if the destination is not found, it looks into the neighbor_lists of its neighbors (i.e. if the destination is the neighbor or the neighbor's neighbor, it sends the packet to that particular neighbor). If it has more than one access to the destination, it checks their EL, if it is more than THRESHOLD_2, it sends the packet to the one with the least number of neighbors, and otherwise it sends the packet to the one with the highest EL. This reduces the MAC contention, balances the load, minimizes the energy wasted by the network and as a result, expends the lifetime of the network. Moreover; this reduces the delay time of the packet delivery, especially between neighboring nodes in the network. However, if an MT wishes to send a packet to another MT that is more than two hops away, first, it sends the packet to its VBS. The VBS looks up its routing table and forwards the packet to the correct neighbor or BMT or the destination. At any time, if the destination is the neighbor or neighbor's neighbor, the packet will be forwarded to that neighbor (see Fig. 2). The sent packet contains the destination address.

```
if((DEST is my neighbor))
  send the packet to it;
else if(DEST is my neighbor's neighbor){
    if(there is more than one neighbor has an access to
    the DEST){
      if(EL of the neighbor > THRESHOLD_2)
        send the packet to the one with the least number
    of neighbors;
      else
        send the packet to the one with the highest EL;
    }
}
```

Fig. 2: First step of packet forwarding Decision Algorithm by all MTs at any time

If the BMT is a zone_MTand the destination is more than two hops away, it broadcasts the destination to all VBSs and free_MTs in its transmission range. If at least one of them has an access to the destination, which is most probably the case, it replies to it. The BMT goes the first reply and ignore the other replies. If the wait time expires, it sends the packet to its VBS.

IV. Network Model

An ad hoc network is modeled as a graph G = (N, L), where N is a finite set of nodes and L is a set of undirected links. The routing protocol uses only bi-directional links.

Now, we are modeling Virtual Base Station On-demand (VBS-O) routing protocol.

- A node n_i has a set of neighbors, $NB_i = \{n_j \in N : (n_i, n_j) \in L\}$
- The bandwidth partitioned into a set of time periods, Tx = {tx_1, tx_2, tx_3, …, tx_m}, which represents the time when medium is occupied.
- The transmission schedule of a node n_i is defined as the set of periods TTx_i in which it transmits
- The set of nodes Rx_i^k, which is n_i transmission targets set (receivers) in period Tx_k, $Tx_k \in TTx_i, Rx_i^k \in NB_i$
- The set $RxTx_i = \{tx_k \in Tx : n_i \in Rx_j^k, n_j \in NB_i\}$, is the set of periods where node n_i is required to receive from its neighbors
- Let $TN^k = \{n_i \in N, tx_k \in TTx_i\}$ be the set of nodes transmitting in period tx_k.

The period of TTx is the collection $\{TTx_i : n_i \in N\}$

To ensure successful transmission:

If node n_i transmits in period tx_k, $(n_i \in TN^k)$ for every node $n_j \in Rx_i^k$, $NB_i \cap TN^k = \{n_i\}$ and $n_j \notin TN^k$

In other words, when node n_i transmits to n_j in period tx_k, n_j itself does not transmit and n_i is the only transmitting neighbor of n_j in that time period.

Definitions:

Given all the terminals initially have fully charged batteries, the maximum allowed energy dissipated per second so as to force the nodes to operate for *h* hours, provided that the network life time is at least h hours.

1. A VBS V_i has a set of MTs, $MT_i = \{(n_i, V_i) \in N, n_i \in V_i, (n_i, V_i) \in L\}$, provided that n_i is within the transmission range of V_i
2. Given all the terminals initially have fully charged batteries, the maximum allowed energy dissipated per second so as to force the nodes to operate for *h* hours, provided that the network life time is at least h hours.

   Maximum flow threshold per second = $\frac{N * battery\_capacity}{h * 3600}$

   where N = total number of nodes in the network,
   h = number of hours (network life time).
3. Each node in the network, which is served by VBS and requires the assistance of its VBS, should expect the following delays and constraints:
   i. Sense the medium, if busy (DIFS + random back off).
   ii. Interference of neighboring nodes.
   iii. If VBS idle (sending packets, hello messages, …etc).
   iv. VBS above Threshold_3.
   v. VBS is still in the transmission range.
   vi. For BER = 10^{-6}, Differential Quadrature Phase Shift Keying (DQPSK) modulation [7]: where, E_b/N_o is the measure of signal to noise ratio for a digital communication system. It is measured at the input to the receiver and is used as the basic measure of how strong the signal is.

We use Energy per Bit (E_b) to Noise Spectral Density (N_o) (E_b/N_o) and the carrier to noise ratio (C/N) to find out how much transmitter power we will need. We use DQPSK modulation scheme and transmit 2 Mbps with a carrier frequency of 2450 MHz. It will have a 30 dB fade margin and operate within a reasonable bit error rate (BER) at an outdoor distance of 100 meters.

4. To the transmit power is to:
- Determine E_b/N_o for the desired BER.
- Convert E_b/N_o to C/N at the receiver using the bit rate.
- Add the path loss and fading margins.

We first decide what is the maximum BER that we can tolerate. For our example, we choose 10^{-6} figuring that we can retransmit the few packets that will have errors at this BER.

Looking at Fig. 3, we find that for DQPSK modulation, a BER of 10^{-6} requires an E_b/N_o of 11.1 dB.

Now we convert E_b/N_o to C/N using the equation:

$$\frac{C}{N} = \frac{E_b}{N_o} * \frac{f_b}{Bw}$$

Where:
fb is the bit rate.
Bw is the receiver noise bandwidth.

Since we now have the carrier-to-noise ratio, we can determine the necessary received carrier power after we calculate the receiver noise power.

Noise power is computed using Boltzmann's equation:

$$N = kTB$$

Where:
k is Boltzmann's constant = 1.380650×10^{-23} J/K;
T is the effective temperature in Kelvin, and
B is the receiver bandwidth.

5. For BER=10^{-6}, DQPSK modulation: E_b/N_0=11.1dB
6. Calculate E_b/N_0 from:
   a. X=SNR*W/RATE.
   b. If X<value of E_b/N_0 found in (2), then reject it…else accept packet.

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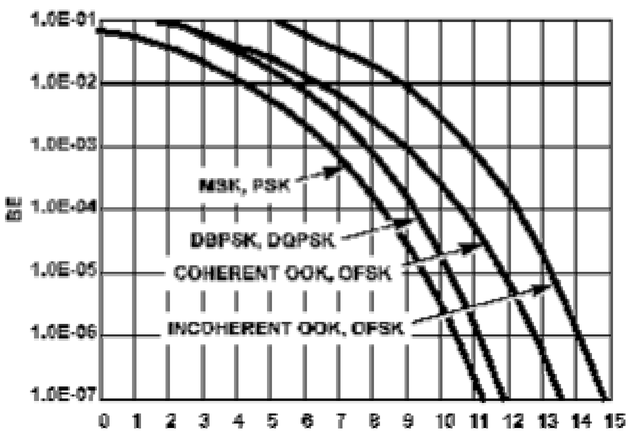


Fig. 3 (BER vs E_b/N_o)

7. Receiver sensitivity:

   $$Pw_{rx\_min} = receiver\_noise\_floor + SNR$$

   a. Receiver_noise_floor = N + noise figure; N = kTB, noise figure = 15 dB
   b. Path Loss (PL) = $10*\log_{10}(4\pi d/\lambda)$; d_{max} = maximum possible distance between transceivers
8. $Pw_{tx\_max} = Pw_{rx\_min} + PL + fade\_margin$
9. $Pw_{rx} = Pw_{tx} \cdot \frac{\lambda_0^2}{(4\pi d)^2}$; Pw_{rx} is measured by receiver
10. Compute d
11. Find $Pw_{tx\_min\_prev}$ for d, Pw_{rx_min}
    a. Before an intermediate node (j, for example) on the route forwards it to the next node towards S it enters $Pw_{tx\_min\_prev}$ calculated in (9)
    b. Node i uses $Pw_{tx\_min\_prev}$ entered by j to calculate its $Pw_{tx\_min\_next}$.
12. $\sum_{e \in n_j} f(e) = f_1(Pw_{tx\_min\_next}) + \sum_{e \in n_j - \{j\}} f_2(Pw_{tx\_min\_next}, R_{e,j})$
13. $\therefore Pw_{tx\_min\_next}$ is used for energy consumption calculations by source node, and $Pw_{tx\_min\_prev}$ is used by the next node to the source to calculate its own $Pw_{tx\_min\_next}$.

V. SIMULATION MODEL AND PERFORMANCE METRICS

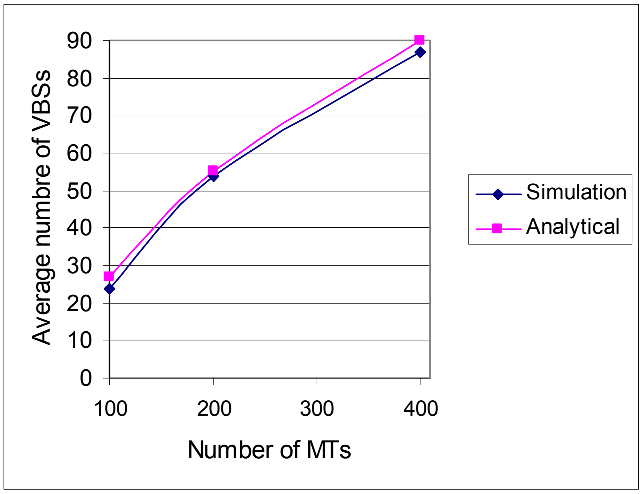
A packet-level discrete-event simulator is developed in order to monitor, observe and measure the performance of the VBS-O/WEAC protocols. The simulator is written using the Java programming language. All the simulation experiments are conducted for ad hoc networks with 100, 200, and 400 mobile terminals. Initially, each mobile station is assigned a unique node ID and a random position in the x-y plane. The simulators measured the following noteworthy statistical performance metrics:

1. *Average Number of VBSs* - The smaller this number, the more the number of mobile nodes that have to be served by each VBS, therefore the distribution of the load will be uneven, and some node drains their batteries much faster than others.
2. Average VBS Duration - The average time duration (in seconds) for which a mobile node remains a VBS. This is a very important performance measure since it is a measure of system stability. The larger the duration, the more stable the scheme. However the duration has to be continuous, so this metric itself does not give the right measure. Another metric should be in parallel along with it to get the correct measure.
3. Number of VBS elections - This metric shows us how often a VBS is being elected. Therefore, the smaller this number the more stable the network. This metric together with the previous one give the true measure of stability.
4. The left power in each node at the end of simulation - This metric shows us how fair the scheme is in exhausting the energy through out the network. We calculate the standard-deviation of the energy level of all MTs at the end of the simulation experiments. Therefore, the smaller the difference, the fairer the scheme.

The performance metrics are set up for wireless mobile ad hoc networks, which cover a 7000 x 7000 unit grid. The wireless transmission range of the mobile nodes is 250 units. The velocity of the mobile nodes is uniformly distributed between 0 and 5 units/second, and the nodes are allowed to move randomly in any direction. THRESHOLD_1 is set to 75%, THRESHOLD_2 to 45%, and THRESHOLD_3 to 25% of the maximum power of the battery. In the case of PA-VBS THRESHOLD_2 is set to 25% and it does not have THRESHOLD_3. Each simulation is run for 6 simulated hours, and the network is sampled every 2 seconds. 95% confidence intervals has been obtained. Since such intervals are very small, they are not explicitly shown in the performance figures. The results of the corresponding experiments are compared against mathematical model. In the analytical part, we use the power formulas that we derived in the simulator to calculate the minimum power.

VI. SIMULATION RESULTS

Fig. 4 shows that the average number of VBSs in the analytical part is slightly higher than that of the simulation part. This is because we did not take into account the gain of the transmitting and receiving antennas in our model. Fig. 5 shows that duration of clusterheads in case of the analytical part is slightly more than the simulation part. This is because of the same reason in the Fig. 4. Fig. 6 shows that the number of elections in the case of the simulation part is slightly higher than that of the analytical part, due to the same reason of the previous Figs. Fig. 7 shows that the standard deviation of the power at the end of the simulation in the case of the simulation is less than that of the analytical part, due to the



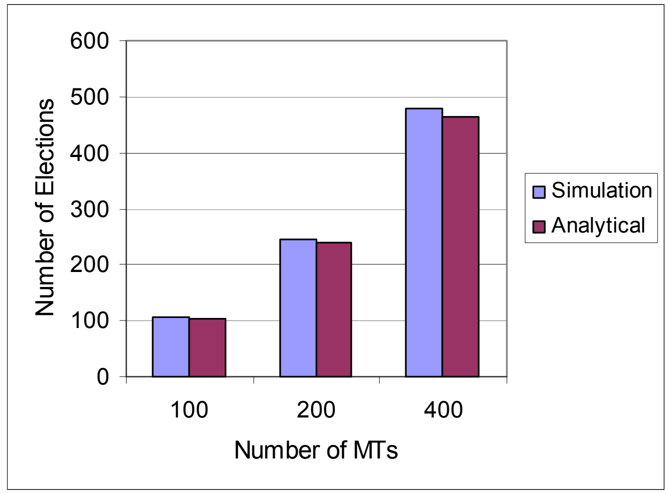


Fig. 6: Impact of network on clusterheads elections

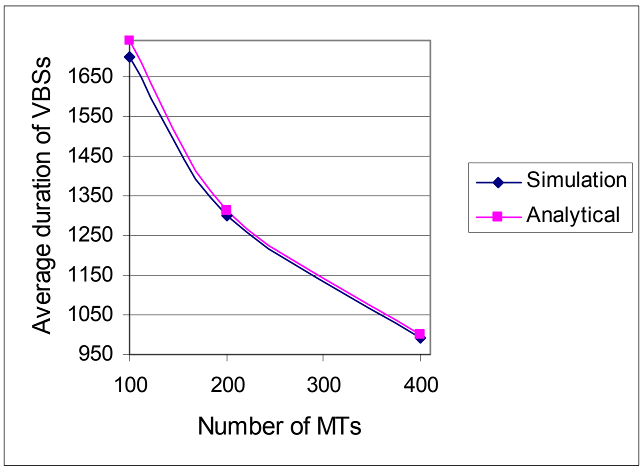


Fig. 5: Impact of network on average duration of clusterheads

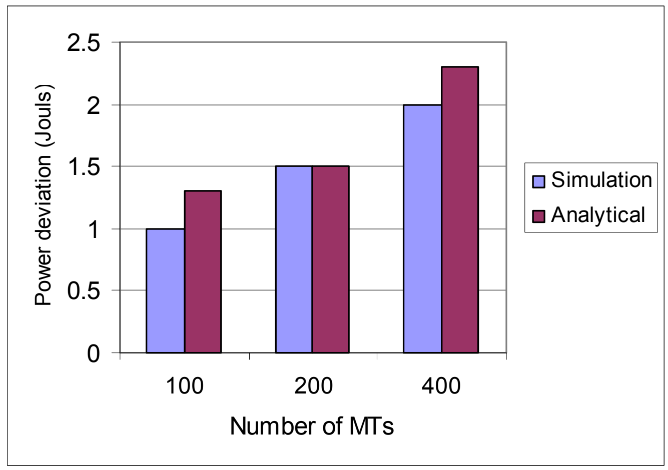


Fig. 7: Impact of network on standard deviation on left power

reason of the previous Figs.

VII. Conclusions

In this paper we have explained very brief the Warning Energy Aware Clusterhead (WEAC) infrastructure protocol together with the Virtual Base Station On-Demand (VBS-O) routing protocol. Also we have derived a mathematical model for VBS-O protocol, and obtained equations to calculate the minimum power required for transmission, in order to enlarge the lifetime of the network. However, Figs. 4-7 show that our model and simulator are producing very close results. Therefore, the outputs of our simulator are acceptable and satisfactory results.

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