Localized Broadcast Oriented Protocols with Mobility Prediction for Mobile Ad Hoc Networks

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Abstract. Efficient broadcasting protocols aim to determine a small set of forward nodes to ensure full coverage. Position based broadcast oriented protocols, such as BIP, LBIP, DBIP and LDBIP work well in static and quasi static environment. While before they can be applied in general case where nodes move even during the broadcast process, the impact of mobility should be considered and mobility control mechanism is needed. In existing mobility management, each node periodically sends "Hello" message and based on received messages construct local view which may be updated at actual transmission time. In this paper, we proposed proactive and predictive mobility control mechanism: node will only send request to collect neighbors' info before transmission which conserves energy consumption of periodical "Hello" messages; once receiving location request command, nodes will send twice at certain interval; based on received locations, nodes will predict neighbors' position at future actual transmission time, use predicted local view to construct spanning tree and do efficient broadcast operation. We propose localized broadcast oriented protocols with mobility prediction for MANETs, and simulation result shows new protocols can achieve high coverage ratio.

1 Introduction

Broadcasting a packet to the entire network is a basic operation and has extensive applications in mobile ad hoc networks (MANETs). For example, broadcasting is used in the route discovery process in several routing protocols, when advising an error message to erase invalid routes from the routing table, or as an efficient mechanism for reliable multicast in a fast-moving MANET. In MANETs with the promiscuous receiving mode, the traditional blind flooding incurs significant redundancy, collision, and contention, which is known as the broadcast storm problem [1].

We study position-based efficient broadcast protocols in which location information facilitates efficient broadcasting in terms of selecting a small forward node set and appropriate transmission radiuses while ensuring broadcast coverage. The optimization criterion is minimizing the total transmission power. Broadcast oriented protocols consider the broadcast process from a given source node. For instance, Wieselthier et al. [2] proposed greedy heuristics which are based on Prim's and Dijkstra's algorithms. The more efficient heuristic, called BIP [2] for broadcasting incremental power, constructs a tree starting from the source node and adds new

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nodes one at a time according to a cost evaluation. BIP is "node-based" algorithm and exploits the "wireless broadcast advantage" property associated with omni-antennas, namely the capability for a node to reach several neighbors by using a transmission power level sufficient to reach the most distant one. Applying the incremental power philosophy to network with directional antennas, the Directional Broadcast Incremental Power (DBIP) algorithm [3] has very good performance since the use of directional antennas provide energy savings and interference reduction.

All the protocols that have been proposed for broadcast can be classified into two kinds of solutions: centralized and localized. Centralized solutions mean that each node should keep global network information and global topology. The problem of centralized approach is that mobility of nodes or frequent changes in the node activity status (from "active" to "passive" and vice-versa) may cause global changes in topology which must be propagated throughout the network for any centralized solution. This may results in extreme and un-acceptable communication overhead for networks. Hence, because of the limited resources of nodes, it is ideal that each node can decide on its own behavior based only on the information from nodes within a constant hop distance. Such distributed algorithms and protocols are called localized [4-8]. Of particular interest are protocols where nodes make decisions based solely on the knowledge of its 1-hop or 2-hops neighbors to them. LBIP [9] (Localized Broadcast Incremental Power) and LDBIP [10] (Localized Directional Broadcast Incremental Power) are localized algorithms which are respectively based on BIP and DBIP.

However, all above broadcast schemes assume either the underlying network topology is static or quasi-static during the broadcast process such that the neighborhood information can be updated in a timely manner. In this paper we consider a general case where nodes move even during the broadcast process, making it impractical to utilize centralized algorithms. However, experiment results show that existing localized algorithms also perform poorly in terms of delivery ratio under general case where nodes move even during the broadcast process. There are two sources that cause the failure of message delivery: collision, the message intended for a destination collides with another message which can be relieved by a very short (1ms) forward jitter delay; mobile nodes, a former neighbor moves out of the transmission range of the current node (i.e., it is no longer a neighbor).
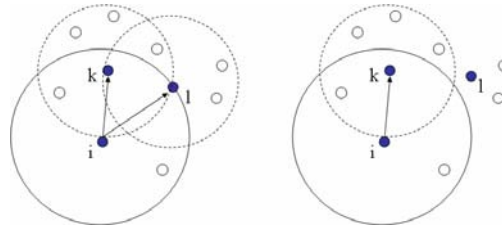
Fig. 1. Impact of mobility on delivery ratio

In Fig. 1, when node l moves out of the transmission range of i, the nodes along the branch rooted at l of the broadcast tree will miss the message. The majority of delivery failures are caused by mobile nodes. Therefore before localized algorithms can be applied in general mobile scenario, certain mobility control mechanism is

needed which inversely may force original localized algorithms to be modified to adapt to it. In most existing mobility management, each node emits a periodic "Hello" message to advertise its presence and position at a fixed interval Δ. "Hello" intervals at different nodes are asynchronous to reduce message collision. Each node extracts neighborhood information from received "Hello" messages to construct a local view of its vicinity (e.g., 2-hop topology or 1-hop location information).

There are three main problems in existing mechanisms: 1) Energy consumption problem, each node periodically emitting "Hello" message will cause a lot of energy consumption; 2) Updated local view: within "Hello" message interval, nodes moving will cause updated neighborhood information; 3) Asynchrony problem: asynchronous sample frequency at each node and asynchronous "Hello" intervals will cause asynchronous position information for each neighbor in certain local view.

In this paper we propose a unique proactive and predictive solution to address main problems in existing mechanisms: 1) Proactive neighbors' location collection to conserve energy: node will only send location request before transmission which conserves the energy consumption of periodic "Hello" messages; 2) Mobility prediction mechanism to get neighborhood information at future actual transmission time: once receiving location request command, nodes will send location twice at certain interval; based on received neighborhood location information, nodes will predict neighbors location information in future actual emitting time T, use this predicted information to construct spanning tree and do efficient broadcast operation in future time T; 3) Synchronization: since we predict all neighbors location information at the same time T, therefore we achieve synchronization for all neighbors. We apply above mobility management mechanism in localized broadcast oriented protocols and simulation results show that our mobility prediction mechanism greatly improved coverage ratio.

The remainder of the paper is organized as follows: In Section 3, we present our localized broadcast oriented protocols with our proposed mobility prediction model with omni and directional antennas. Section 4 shows our simulation work and results. In Section 5, we present the conclusion.

2 Localized Broadcast Oriented Protocols with Mobility Prediction

The application of our proposed mechanism in localized broadcast oriented protocols is as follows:

- Source node S initiates its neighborhood location table and emits location request (*LR*) using omni-antenna with maximum transmission range (*MTR*).
- At the same time, S stores its current location (*CL*) in location table A; after a certain time interval $\Delta T1$, stores its current location again in location table B.
- Any node which receives location request, for example U, at once emits its current location using omni-antenna of maximum transmission range with 1st location remark (*1LRM*). After time interval $\Delta T1$, U collects its current location again and emits it with 2nd location remark (*2LRM*).
- S starts receiving neighbors' location information (*NL*). S stores neighbors' location with *1LRM* in table A, and neighbors' location with *2LR* in table B.

- After waits for time interval $\Delta T2$ to guarantee receiving all neighbors' location, S starts to predict own and all neighbors' location at future time T.
- S calculates localized broadcast spanning tree based on predicted future own and neighborhood location information.
- S enters into broadcast process at time T: broadcasting packet P as calculated instruction and also including relay nodes ID.
- Any node, for example V, which receives packet P checks whether it's in relay nodes list. If in rely list, V works as source node; otherwise, does nothing.

Fig.2 is the work flow of the proposed localized algorithm. In the following we will present 4 stages of our algorithm in detail
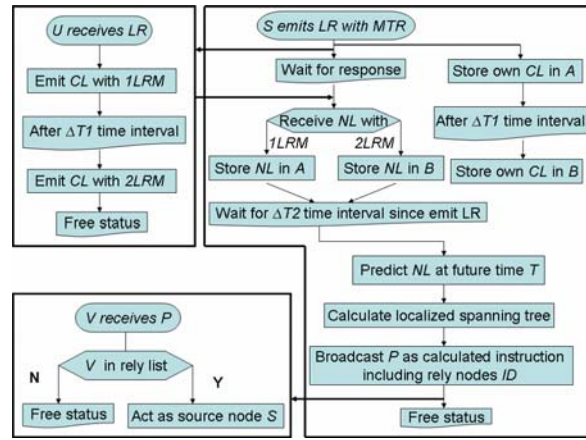

Fig. 2. Work flow of the proposed algorithm

2.1 Proactive Neighbors' Location Collection Stage

Node will only send location request before transmission which conserves the energy consumption of periodic "Hello" messages in most existing mobility mechanisms.
- Source node S emits location request.
- After transmission delay time interval (TD), any node U receives location request and ideally at once emits its current location with $1LRM$. While sometimes there is receiving process delay (ED). After a certain time interval $\Delta T1$, U emits its current location with $2LRM$.
- After waits for time interval $\Delta T2$, S starts to predict all neighbors' location at future actual transmission time T. In Fig. 3 RT represents the redundant time interval for guarantee receiving all neighbors' location information and PD is prediction delay for deciding the value of T.

In Fig.3 we show the time flow of our proactive mechanism.

In our mechanism S needs to set timer with interval $\Delta T2$ to trigger prediction process; U should set timer with interval $\Delta T1$ to trigger the sending of its 2nd current location; S need to set PD to decide the value of T. From above time flow, we can calculate that $\Delta T2 = 2*TD + \Delta T1 + ED + RT$. In ideal model, ED equals zero, TD depends on wireless network and RT can be set depending on designer redundancy

requirement. The main issue for us is how to decide $\Delta T1$ and PD. We propose relationships between those two parameters and average mobile speed v. The principle for those relationships is to predict accurate location at broadcast process time T. As v increases, $\Delta T1$ and PD should become smaller to finish prediction and broadcast before nodes change move direction. Therefore, the formula is:

$$\Delta T1 = \beta \frac{1}{v} + k \, ,$$ (1)

where k represents the minimum time interval and β is the coefficient to adjust the deceleration speed according to designers requirement.

$$PD = \alpha \frac{1}{v} + \Delta \, ,$$ (2)

where Δ represents the minimum space for high mobile speed scenario and α is the coefficient to adjust the deceleration speed according to designers requirement.
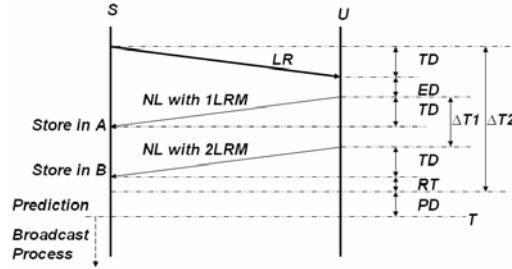

Fig. 3. Time flow of the proposed proactive mechanism

2.2 Mobility Prediction Stage

The objective of mobility prediction is to calculate neighborhood location information at future actual emitting time T, based on location information in table A and B. Node will use this predicted information to construct spanning tree and start efficient broadcast process at time T. Another contribution of our proposed mobility prediction model is that since we predict all neighbors' location information at the same time T, therefore we achieve consistent future view for all neighbors.

Camp et al. [11] gave a comprehensive survey on mobility models for MANETs. They discussed seven different synthetic entity mobility models, among which Random Walk, Random Waypoint and Random Direction are simple linear mobility models. Therefore, we construct our mobility prediction model as shown in Fig. 4.
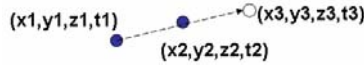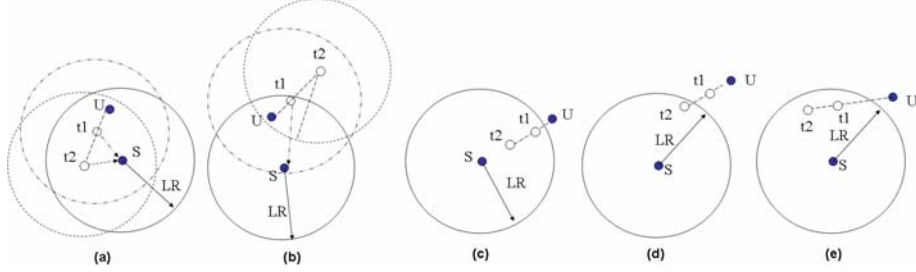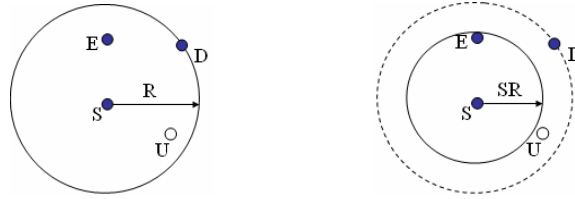

Fig. 4. Mobility prediction Model

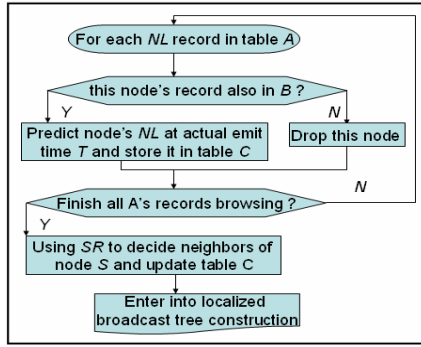If we know location of mobile node S at time $t1$ and $t2$, we can predict nodes' location at time $t3$ by:

$$
\begin{aligned}
x3 &= x1 + \frac{x2-x1}{t2-t1}*(t3-t1) & x3 &= x2 + \frac{x2-x1}{t2-t1}*(t3-t2) \\
y3 &= y1 + \frac{y2-y1}{t2-t1}*(t3-t1) & y3 &= y2 + \frac{y2-y1}{t2-t1}*(t3-t2) \\
z3 &= z1 + \frac{z2-z1}{t2-t1}*(t3-t1) \quad \text{or} \quad & z3 &= z2 + \frac{z2-z1}{t2-t1}*(t3-t2)
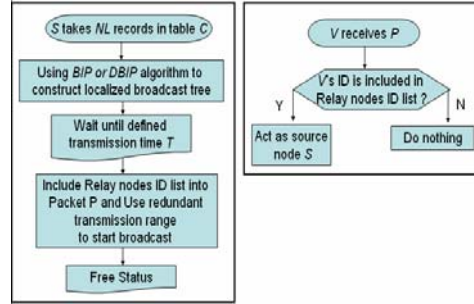\end{aligned}
$$ (3)

Fig. 5. Possible situations for node *U*

Fig. 6. Function of smaller neighborhood range (SR)

Fig. 7. The process of mobility prediction   **Fig. 8.** Work flow of broadcast process

To apply above mathematic model to mobility prediction process, we have to take locations respectively from table *A* and *B* for certain node *U*. We have stored location at time *t1* in table *A* and location at time *t2* in table *B*. Fig. 5 lists the possible situations for node *U*. Fig. 5 (a) is the normal situation where node *U* is the neighbor of *S* at both time *t1* and *t2*. Then we can apply our prediction model with node *U*'s record in both table *A* and *B*. In Fig. 5 (b), node *U* moves out of the neighborhood area of node *S* at time *t2*. Therefore, we can just drop the node which only appears in table *A*. However, the most serious situation is that when node *S* emits location request, node *U* doesn't receive location request while after that at *t1* or *t2* time, *U* is neighbor of node *S*. Fig. 5 (c) (d) (e) display those situations where node *U* can appear at any position of the neighborhood of node *S*. However, the probability greatly decreases as distance between two nodes decreases. Therefore, we can only correct the problem when node *U* appears in the outer neighborhood area of node *S*. Our solution is after prediction process to decide neighbors of node *S* by smaller neighborhood range stand (*SR*). Then we can guarantee accurate neighborhood location information with high probability. Fig. 6(a) shows the predicted local view of node *S*, where node *U* is

not include even in fact it is the neighbor of S . By applying SR, node S achieves smaller but accurate local view which is shown in Fig. 6(b)

The value of SR is related to average mobile speed v. We propose a relationship formula which can be written as:

$$SR = R - kv,\qquad\qquad\qquad (4)$$

where R represents original maximum transmission range and k is the coefficient to adjust the slope according to designers' requirement.

According to all above analysis, we propose the process of mobility prediction which is shown in Fig. 7.

2.3 Broadcast Process Stage

In Fig. 8 we show the work flow of broadcast process. We absorb the redundant proposal of Wu and Dai [12 -16] to use a longer transmission range to start real broadcast process. A pseudo code of BIP is shown in Fig. 9.


Input: given an undirected weighted graph $G(N,A)$, where N: set of nodes, A: set of edges
Initialization: set $T:=\{S\}$ where S is the source node of broadcast session. Set $P(i):= 0$ for all $1 \leq i \leq |N|$ where $P(i)$ is the transmission power of node i.
Procedure:
while $|T| \neq |N|$
      do find an edge $(i,j) \in T \times (N-T)$ such that
        incremental power $\Delta P_{ij} = d_{ij}^{\alpha} - P(i)$ is minimum.

      add node j to T, i.e., $T := T \cup \{j\}$.
      set $P(i) := P(i) + \Delta P_{ij}$.

Fig. 9. Pseudo code of BIP

The incremental power philosophy, originally developed with omni antennas, can be applied to tree construction in networks with directional antennas as well. At each step of the tree-construction process, a single node is added, whereas variables involved in computing cost (and incremental cost) are not only transmitter power but beam width θ as well. In our simple system model, we use fixed beam width θ_f, that means for adding a new node, we can only have two choices: set up a new directional antenna to reach a new node; raise length range of beam to check whether there is new node covered or not. A pseudo code of DBIP is shown in Fig. 10.

Input: given an undirected weighted graph $G(N,A)$, where N: set of nodes, A: set of edges
Initialization: set $T:=\{S\}$ where S is the source node of broadcast session. Set $P(i):= 0$ for all $1 \leq i \leq |N|$ where $P(i)$ is the transmission power of node i.
Procedure:
while $|T| \neq |N|$
      do find an edge $(i,j) \in T \times (N-T)$ with fixed beam width θ_f such that ΔP_{ij} is minimum; if an edge $(i,k) \in T \times T$ raising the length range of beam can cover node $j \in (N-T)$, incremental power $\Delta P_{ij} = d_{ij}^{\alpha} \frac{\theta_f}{2\pi} - P(i)$; otherwise, $\Delta P_{ij} = d_{ij}^{\alpha} \frac{\theta_f}{2\pi}$.
      add node j to T, i.e., $T := T \cup \{j\}$. **set** $P(i) := P(i) + \Delta P_{ij}$.

Fig. 10. Pseudo code of DBIP
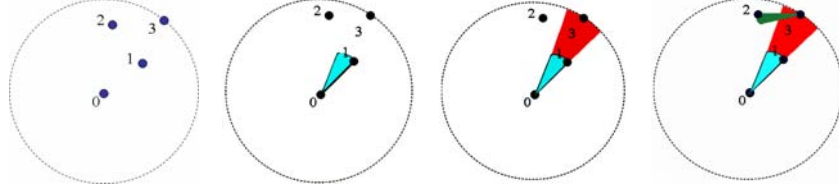
Fig. 11. Nodes addition in LDBIP

Fig. 11(a) shows a simple example of DBIP in which the source node has 4 local neighbor nodes 0, 1, 2, and 3. Node 1 is the closest to Node 0, so it is added first; in Fig. 11(b), an antenna with beam width of θ_f is centered between Node 0 and Node 1.

Then we must decide which node to add next (Node 2 or Node 3), and which node (that is already in the tree) should be its parent. In this example, the beam from Node 0 to Node 1 can be extended to include both Node 1 and Node 3, without setting up a new beam. Compared to other choices that setting up a new beam from Node 0 to Node 2, or from Node 1 to Node 2, this method has minimum incremental power. Therefore, Node 3 is added next by increasing the communication range of Node 0 and Node 1. In Fig. 11(c), finally, Node 1 must be added to the tree. Three possibilities are respectively to set up a new beam from Node 0, 1, 3. Here we assume that Node 3 has minimum distance. Then in Fig. 11 (d) we set up a new beam from Node 3 to Node 2.

3 Performance Evaluation

In this section, we present the performance evaluation of localized broadcast oriented protocols with our mobility prediction.

3.1 Simulation Environment

We use ns-2.28 [17] and its CMU wireless extension as our simulation tool and assume AT&T's Wave LAN PCMCIA card as wireless node model which parameters are listed in table 1.Since our purpose is to observe the effect of our mobility control mechanism, all simulations use an ideal MAC layer without contention or collision. Simulations apply ideal physical layer, that is, free space and two ray ground propagation model where if a node sends a packet, all neighbors within its transmission range will receive this packet after a short propagation delay. Table 2 displays parameters for wireless networks which are used in our simulation. In our simulation network, 100 nodes are placed in a fixed area network (900mx900m) which is relatively dense network. For each measure, 50 broadcasts are launched.

Table 1. Parameters for wireless node model

	AT&T's Wave LAN PCMCIA

Frequency	2.4GHZ
Maximum transmission range	250m
Maximum transmit power	0.281838 W
Receiving power	0.395 watts
Transmitting power	0.660 watts
Omni-antenna receiver/transmitter gain	1db
Fixed beam width of directional antennas	30°
Directional-antenna receiver/transmitter gain	58.6955db
MAC protocol	802.11
Propagation model	free space / two ray ground

Table 2. Parameters for wireless networks

| Parameters	Value
Simulation Network Size	900mx900m
Nodes number	100
Simulation time	50m
Packet size	64k
Transmission delay	25us

The mobility model used in our simulation is random waypoint model [11, 18-21] which is widely used in simulating protocols designed for mobile ad hoc networks. In this model, a mobile node begins by staying in one location for a certain period of time (i.e., a pause time). Once this time expires, the mobile node chooses a random destination in the simulation area and a speed that is uniformly distributed between *[minspeed, maxspeed]*. The mobile node then travels toward the newly chosen destination at the selected speed. Upon arrival, the mobile node pauses for a specified time period before starting the process again. In addition, the model is sometimes simplified without pause times.

3.2 Simulation Results

To evaluate the performance of localized broadcast protocols with mobility control management, we define some parameters: RAR, EC and SRB. The RAR (Reach Ability Ratio) is the percentage of nodes in the network that received the message. Ideally, each broadcast can guarantee 100% RAR value. While in mobile environment because of nodes mobility, RAR may be less than 100% and then RAR becomes more important in performance evaluation in mobile ad hoc networks. To investigate energy efficiency issue, we observe EC (total power consumption) over the network when a broadcast has occurred. In addition, under mobile simulation environment, the energy consumption includes not only the energy consumption for broadcasting message, but also that for propagation in mobility control process. We also observe the FNR (Forward Node Ratio) which is the percentage of nodes in the network that retransmit the message. A blind flooding has a FNR of 100%, since each node has to retransmit the message at least once.

In our simulation, nodes average moving speed varies from 0m to 160m per second. We compare protocol performance when it doesn't employ mobility prediction
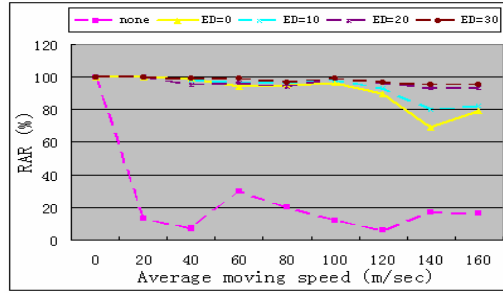
mechanism with that when it applies prediction mechanism while redundant transmission range varies from 0 to 30. In figures, "none" presents the simulation result when protocol doesn't employ mobility management mechanisms and "ED" is the redundant transmission range.
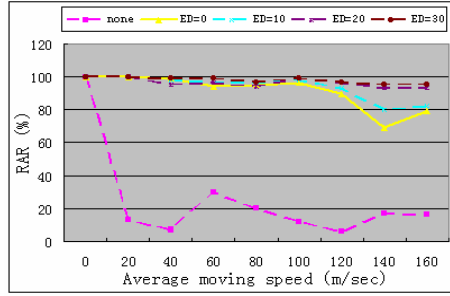

Fig.12. RAR of LBIP
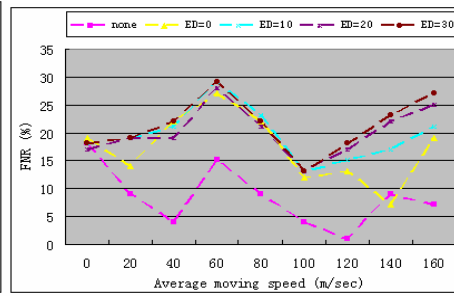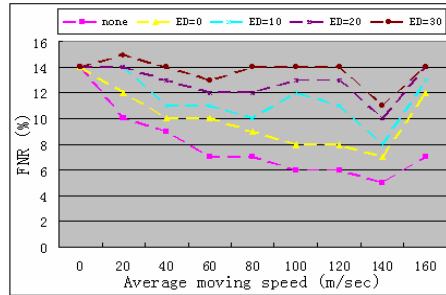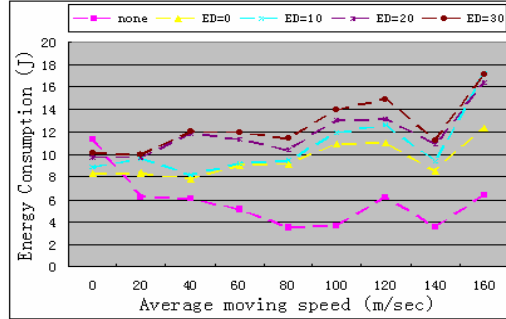

Fig.13. FNR of LBIP

Fig.14. EC of LBIP

Fig.12-14 shows LBIP performance comparison. In Fig.12, it's obvious that once employ our predictive mechanism, LBIP can get very high broadcast coverage ratio. As redundant transmission range increases, the RAR can nearly reach 100%. While Fig 13 shows that at that time forward nodes ratio will also increases, which reflects energy consumption increase shown in Fig. 14. The reason why energy consumption is very low when we didn't apply our proposal is that at that time retransmission nodes number decreases greatly and few nodes really receive message because of nodes mobility, inaccurate location information and corresponding inaccurate retransmission instruction.
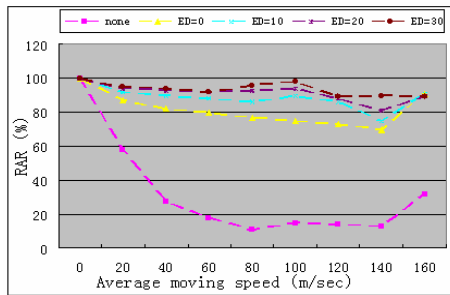
Fig.15. RAR of LDBIP

Fig.16. FNR of LDBIP

Fig.17. EC of LDBIP

Fig.15-17 shows LDBIP performance comparison. In Fig.15, it's obvious that once employ our predictive mechanism, LDBIP can get high broadcast coverage ratio. As redundant transmission range increases, RAR value also increases. While compare Fig.12 and Fig 15, we can find that our predictive mechanism works better in LBIP than in LDBIP. In other words, our proposal works better in networks with omni-antennas than that with directional antennas. That's because omni-antennas have much more coverage redundancy. While directional antennas can conserve energy consumption and avoid interference, we can see from Fig. 14 and 17 that the energy consumption of LDBIP is nearly 50% of that of LBIP. In Fig 16, the FNR also correspondingly reflects LDBIP can conserver more energy since fewer nodes will do retransmission compared to LBIP. Also the energy consumption of LDBIP is very low when we didn't apply our proposal. The reason is the same with that in LBIP.

4   Conclusions

In this paper, we proposed a new mobility control mechanism which is proactive and predictive. The goal of our mechanism is to guarantee high broadcast coverage and energy efficient issue. Therefore, in our proposal we employ proactive Request-Response model to collect neighbors' location information to save energy which is consumed for periodic "Hello" messages in previous existing mobility control mechanisms. We propose mobility prediction mechanism to predict the neighbors' actual location at the actual transmission time by which we avoid updated information. We apply our mobility prediction mechanism into localized broadcast oriented protocols, such as LBIP and LDBIP. To apply our mechanism we modified existing protocols to adapt to our mechanism and simulation results show that our proposal greatly increased the broadcast coverage of localized broadcast protocols.

Acknowledgement

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