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A Generic Localized Broadcast Framework in Mobile Ad Hoc Ubiquitous Sensor Networks

Hui XU[†a)], **Brian J. D'AURIOL**[†], *Nonmembers*, **Jinsung CHO**[†], **Sungyoung LEE**[†], *Members*,
and **Byeong-Soo JEONG**[†], *Nonmember*

SUMMARY In this paper, we investigate the critical low coverage problem of position aware localized efficient broadcast in mobile ad hoc ubiquitous sensor networks and propose a generic framework for it. The framework is to determine a small subset of nodes and minimum transmission radiuses based on snapshots of network state (local views) along the broadcast process. To guarantee the accuracy of forward decisions, based on historical location information nodes will predict neighbors' positions at future actual transmission time and then construct predicted and synchronized local views rather than simply collect received "Hello" messages. Several enhancement technologies are also proposed to compensate the inaccuracy of prediction and forward decisions. To verify the effectiveness of our framework we apply existing efficient broadcast algorithms to it. Simulation results show that new algorithms, which are derived from the generic framework, can greatly increase the broadcast coverage ratio.

key words: *broadcast, localized efficient protocols, mobility prediction, mobile ad hoc ubiquitous sensor network*

1. Introduction

Broadcasting a packet to the entire network is a basic operation and has extensive applications in mobile ad hoc ubiquitous sensor networks, composed of possibly mobile devices such as sensors, laptops, or PDAs. As the considered devices rely on batteries with limited capacity, the most important criterion when designing communication protocols is obviously energy conservation.

Efficient broadcasting aims to select a small part of nodes rather than all nodes in network as forward nodes and minimum transmission radiuses to minimize the total energy consumption for a broadcast task while ensuring broadcast coverage. Among all kinds of efficient protocols position aware protocols in which location information facilitates broadcast tree construction basically have best energy saving performance. Because of the limited resources of nodes, it is ideal that each node can decide its own behavior only based on the information from neighbor nodes. Such distributed algorithms and protocols are called localized [1]–[5].

In most existing localized protocols for mobile ad hoc ubiquitous sensor networks, each node emits "Hello" messages to advertise its presence and update its location. The update protocols basically can be classified into two types: periodical update and conditional update. Each node extracts neighborhood information from received "Hello" messages to construct a local view of its vicinity (e.g., 1-hop location information). However, there are two main problems in those schemes. 1) Outdated local view: when consider a general case where broadcasts occur within "Hello" message interval, while nodes move during this interval, broadcast tree calculation will be based on outdated neighborhood information. Especially, for localized protocols, since forward nodes cooperate with each other to make forward decisions, broadcast processing delay cannot be neglected. Therefore nodes movement during broadcast can also cause outdated local view. 2) Asynchronous local view: asynchronous location information for each neighbor in local view is caused by asynchronous clock at each node, asynchronous "Hello" messages and message intervals in periodical update, and different "Hello" intervals in conditional update. The forward decisions based on outdated and asynchronous local view may be inaccurate and hence cause delivery failure which can induce poor coverage of broadcast task.

So far, no generic framework can capture a large body of distributed broadcast algorithms and deal with above low broadcast coverage problem. In this paper we provide a generic framework from which existing efficient broadcast algorithms can be reformed to new distributed algorithms which have much more higher broadcast coverage than existing ones. In this framework, each node maintains an update table to learn its neighborhood; when a broadcast is triggered, the source node will predict a synchronized local view at scheduled emission time based on the information in its update table and employ existing algorithms to calculate broadcast tree; the broadcast packet can carry a small amount of relay instructions; the status of other nodes, forward or non-forward, is determined by those relay instructions; forward nodes will act as source node and continue the broadcast process.

The remainder of this paper is organized as follows: Sect. 2 presents related work and the motivation of our work. In Sect. 3, we propose a generic localized broadcast framework and present in detail each step of that framework. Section 4 shows simulation work and its results. In Sect. 5, we conclude this paper.

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[†] The authors are with the Dept. of Computer Engineering, Kyung Hee University, Yongin, Kyunggi 449-701, Korea. Prof. Jinsung Cho is the corresponding author.
a) E-mail: xuhui@oslab.khu.ac.kr

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2. Related Work and Background

2.1 Mobility Management

The nodes mobility has great effect on the performance and capacity of mobile ad hoc networks, which is discussed in [6] and [7].

Much work on mobility management has been done for the design of routing protocols. In the work of Su et al. [8], location information is used to estimate the expiration time of the link between two adjacent hosts which determines the selection of route path. [9] presents a location-delay prediction scheme to predict the location at a given instant, which assists QoS routing decisions. However, very little work has tried to maintain accurate neighborhood information to assist the route path selection. One exception is [10], where a stable zone and a caution zone of each node have been defined based on the node's position, speed, and direction information obtained from GPS.

A little work on mobility management has been done for the design of broadcasting protocols. Wu and Dai [11]–[15] have taken the outdated and asynchronous local view caused by nodes' movement within "Hello" message interval into consideration. They proposed a conservative "two transmission radius" method to compensate the outdated local view. First, they give a minimal transmission range that maintains the connectivity of the virtual network constructed from inaccurate local views. Then, use a longer transmission radius to form a buffer zone that guarantees the availability of logical links in the physical network. However, above approaches are passive since they just try to compensate the inaccuracy of local view rather than predict accurate future local view.

2.2 Background

In mobile ad hoc ubiquitous sensor networks the update protocol [9] can be classified into periodical update with fixed time interval and conditional update when there is considerable direction change in the node's motion velocity or direction.

Conditional Update. Suppose that the periodic check for a particular node occurs at time t_c with actual location at (x_c, y_c, z_c). Further suppose that its most recent update was generated at time t_{1h} with location (x_{1h}, y_{1h}, z_{1h}), speed v and direction (d_x, d_y, d_z). Then expected location (x_e, y_e, z_e) at t_c can be calculated as

$$\begin{cases} x_e = x_{1h} + (t_c - t_{1h}) \cdot v \cdot d_x \\ y_e = y_{1h} + (t_c - t_{1h}) \cdot v \cdot d_y \\ z_e = z_{1h} + (t_c - t_{1h}) \cdot v \cdot d_z. \end{cases} \tag{1}$$

Now check whether the deviated distance is larger than δ or not. If $\sqrt{(x_e - x_c)^2 + (y_e - y_c)^2 + (z_e - z_c)^2} > \delta$ update should be generated. In addition, δ is set by designers.

3. A Generic Localized Broadcast Framework

Here we propose a generic localized broadcast framework as shown in Fig. 1. This is a dynamic approach in which nodes collaborate with each other to calculate relay instructions and complete broadcast tasks. In the framework there are three blocks: mobility management, broadcast tree construction and broadcast process. In the following subsections, we will present them in detail.

3.1 Mobility Management

In mobile ad hoc ubiquitous sensor networks, each node maintains an update table to record received "Hello" messages from its neighbors; when a broadcast is triggered at a node S, first S will schedule appropriate actual transmission time and then make use of historic information in update tables to construct a synchronized local view based on the prediction of neighbors' future locations.

3.1.1 Update Table Management

Tables Contents. The information about its neighborhood stored at any node S is shown in Fig. 2. The update table stores neighbor nodes' ID, the update sequence number, the time the update packet is sent, the time it is received (the two kinds of time will be used to form synchronized local views), the location coordinates contained in the update packet, the velocity (including the speed and direction) and, optionally, other specially needed parameters.

Update Table Maintenance. To make predictions, a node S needs to store the latest two updates of its each neighbor. In addition, in order to set up its local view, the node S should first include its own records into the update table. To maintain two updates, when receive a message from a node U and there is no existing record for it, the node S will add this new message into the update table and successively assign one new empty record for this node U as shown in Fig. 2; otherwise, replace one of the node U's two records which has the lower Update Number.

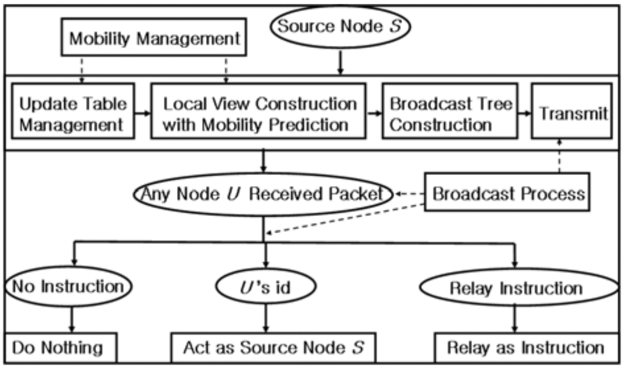
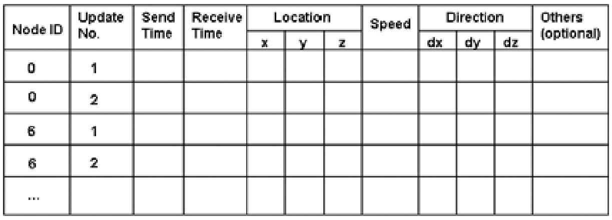


Fig. 1 A generic localized broadcast framework.



Node ID	Update No.	Send Time	Receive Time	Location			Speed	Direction			Others (optional)
				x	y	z		dx	dy	dz	
0	1										
0	2										
6	1										
6	2										
...											

Fig. 2 Update table at S to store location and other information about its neighbors, obtained from their updates.

3.1.2 Local View Construction

When a broadcast is trigged at any node S, node S should make use of update table information to construct a local view for broadcast tree calculation. To address the low broadcast coverage problem caused by outdated and asynchronous local view based on latest received "Hello" messages, we propose to predict the locations of node S and all its neighbors at the future time t_p (with node S's clock) and then construct the local view by collecting the predicted future locations of all the neighbors. Because this local view will be used to calculate transmission instructions for node S and relay instructions for its neighbors, this prediction time should be the node S's actual transmission time (t_b) + broadcast delay time (t_D). Moreover, how to schedule an appropriate actual transmission time (t_b) is also affected by some other factors. This is analyzed in the next separate section. However there are still two issues:

- How to choose the delay time t_D;
- How to calculate other nodes' corresponding prediction time.

The delay time t_D includes not only the wireless network transmission delay t_e but also the packet and transmission processing time t_s. t_e is basically fixed in wireless networks while t_s can vary according to packet size.

To determine any other neighbor node A's prediction time t'_p, we can calculate its time difference with reference node S, t'_d. Then $t'_p = t_p + t'_d$. To get t'_d, we include local sending time t_l in hello messages and also local received time t_r which has been presented in update table management. Then the time difference of A to S can be calculated as $t'_d = t_l - t_r + t_e$ where t_e is the wireless network transmission delay.

3.1.3 Analysis for Prediction Interval

For any node S we define the time difference between its broadcast trigger time and actual transmission time as **prediction interval**. When we schedule an actual transmission time for S, if within the prediction interval neighbor nodes already move out of the transmission range of node S, our prediction scheme will have no meaning. Therefore we analyze the **Transmission Range Dwell Time**, T_{dwell}, the time period within which any neighbor node U stays in the transmission range of node S. R_{dwell} is the rate of crossing the boundary of its transmission range.

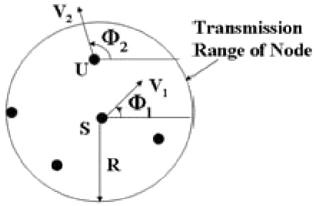


Fig. 3 Analysis model for prediction interval.

Figure 3 shows an analytical model where we assume that node S moves with a velocity $\vec{V_1}$ and node U moves with a velocity $\vec{V_2}$. The relative velocity $\vec{V}$ of node U to node S is given by

$$\vec{V} = \vec{V_2} - \vec{V_1}. \tag{2}$$

The magnitude of $\vec{V}$ is given by

$$V = \sqrt{V_1^2 + V_2^2 - 2\,V_1\,V_2\cos(\Phi_1 - \Phi_2)} \tag{3}$$

where V_1 and V_2 are the magnitudes of $\vec{V_1}$ and $\vec{V_2}$. The mean value of V is given by

$$E[V] = \int_{V_{min}}^{V_{max}}\int_{V_{min}}^{V_{max}}\int_{0}^{2\pi}\int_{0}^{2\pi}\sqrt{v_1^2 + v_2^2 - 2v_1v_2\cos(\phi_1 - \phi_2)}\; f_{V_1,V_2,\Phi_1,\Phi_2}(v_1, v_2, \phi_1, \phi_2)\,d\phi_1 d\phi_2 dv_1 dv_2 \tag{4}$$

where $f_{V_1,V_2,\Phi_1,\Phi_2}(v_1, v_2, \phi_1, \phi_2)$ is the joint pdf of the random variables V_1, V_2, Φ_1, Φ_2, V_{min} and V_{max} are the minimum and maximum moving speeds, and the symbol $E[V]$ is an average value of the random variable V. Since the moving speeds V_1 and V_2 and directions Φ_1 and Φ_2 of nodes S and U are independent, Eq. (4) can be simplified as

$$E[V] = \int_{V_{min}}^{V_{max}}\int_{V_{min}}^{V_{max}}\int_{0}^{2\pi}\int_{0}^{2\pi}\sqrt{v_1^2 + v_2^2 - 2v_1v_2\cos(\phi_1 - \phi_2)}\; f_V(v_1)\,f_V(v_2)\,f_\Phi(\phi_1)\,f_\Phi(\phi_2)\,d\phi_1 d\phi_2 dv_1 \cdot dv_2. \tag{5}$$

If Φ_1 and Φ_2 are uniformly distributed in $(0, 2\pi]$, Eq. (5) can be further rewritten as

$$E[V] = \frac{1}{\pi^2}\int_{V_{min}}^{V_{max}}\int_{V_{min}}^{V_{max}}(v_1 + v_2)\,F_e\left(\frac{2\sqrt{v_1v_2}}{v_1 + v_2}\right)f_V(v_1) \cdot f_V(v_2)\,dv_1dv_2 \tag{6}$$

where $F_e(k) = \int_0^1\sqrt{\frac{1-k^2t^2}{1-t^2}}dt$ is complete elliptic integral of the second kind. Therefore, in the following analysis, we can consider that node S is at rest, and node U is moving at a relative velocity instead of the two nodes moving with their respective velocities.

Assume that nodes are distributed uniformly and nodes' moving direction is distributed uniformly over [0, 2π], from [16] the mean value of R_{dwell} is given by

$$R_{dwell} = \frac{E[V]L}{\pi A} \tag{7}$$

where A is the area of the transmission range and L is the perimeter of this area. Therefore, the average transmission range dwell time is given by

$$E[T_{dwell}] = \frac{\pi A}{E[V]L}. \tag{8}$$

In summary, our prediction interval should be bounded within the time $E[T_{dwell}]$.

3.1.4 Mobility Prediction Models

Once determined each node's corresponding prediction time, we can start to predict their future locations.

Camp et al. [17] have given a comprehensive survey on mobility models for mobile ad hoc ubiquitous sensor networks, from which we can find that in some models before changing direction nodes move linearly. The other models are not precisely linearly movement, while in a segment view, nodes also move linearly. Therefore we propose two **piecewise linear** models and one **nonlinear** model.

Location-based Prediction: Suppose that there are two latest update records for a particular node at time t_{1h} and t_{2h} ($t_{1h} > t_{2h}$) with location information of (x_{1h}, y_{1h}, z_{1h}) and (x_{2h}, y_{2h}, z_{2h}), respectively. Assume at least within two successive update periods the node moves in a straight line with fixed speed (depicted in Fig. 4), we get

$$\begin{cases} \dfrac{x_{1h} - x_{2h}}{t_{1h} - t_{2h}} = \dfrac{x_p - x_{1h}}{t_p - t_{1h}} \\ \dfrac{y_{1h} - y_{2h}}{t_{1h} - t_{2h}} = \dfrac{y_p - y_{1h}}{t_p - t_{1h}} \\ \dfrac{z_{1h} - z_{2h}}{t_{1h} - t_{2h}} = \dfrac{z_p - z_{1h}}{t_p - t_{1h}}, \end{cases} \tag{9}$$

then the location (x_p, y_p, z_p) at a future time t_p can be calculated as

$$\begin{cases} x_p = x_{1h} + \dfrac{x_{1h} - x_{2h}}{t_{1h} - t_{2h}}(t_p - t_{1h}) \\ y_p = y_{1h} + \dfrac{y_{1h} - y_{2h}}{t_{1h} - t_{2h}}(t_p - t_{1h}) \\ z_p = z_{1h} + \dfrac{z_{1h} - z_{2h}}{t_{1h} - t_{2h}}(t_p - t_{1h}). \end{cases} \tag{10}$$

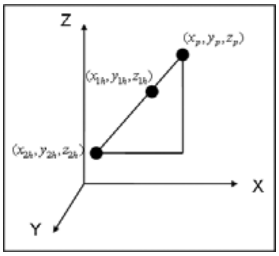


Fig. 4 Location-based prediction model.

However in conditional update networks since the latest update represents considerable changes compared to previous update, this model cannot be used.

Velocity-aided Prediction: Let (x_{1h}, y_{1h}, z_{1h}) and (v'_x, v'_y, v'_z) respectively be the location and velocity of its latest update for a particular node. Assume the node moves with that speed within one update period (depicted in Fig. 5), the location (x_p, y_p, z_p) at a future time t_p can be calculated as

$$\begin{cases} x_p = x_{1h} + v'_x(t_p - t_{1h}) \\ y_p = y_{1h} + v'_y(t_p - t_{1h}) \\ z_p = z_{1h} + v'_z(t_p - t_{1h}). \end{cases} \tag{11}$$

Nonlinear (Constant Acceleration) Model: In high speed mobility networks we can assume the force acting on the node is constant, that is, nodes move with constant acceleration.

Let (x_{1h}, y_{1h}, z_{1h}) at t_{1h} and (x_{2h}, y_{2h}, z_{2h}) at t_{2h} ($t_{1h} > t_{2h}$) be the latest two updates for a particular node. Let (v'_x, v'_y, v'_z) and (v''_x, v''_y, v''_z) respectively be the velocity of those two updates. Now predict the location (x_p, y_p, z_p) at a future time t_p before new update time comes (depicted in Fig. 6). As all know the principle motion law can be formulated as

$$V = v + at \tag{12}$$

and

$$S = vt + \frac{1}{2}at^2 = \bar{v}t = \frac{v + V}{2}t, \tag{13}$$

where S is the displacement, v is the initial velocity and a is acceleration during period t. We employ V denoting the final velocity after period t.

Assume the fixed acceleration is (a_x, a_y, a_z), applying above principle to X-dimension, we can obtain

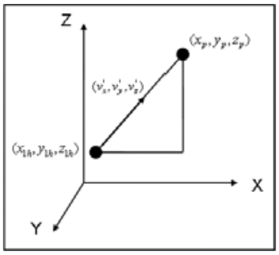


Fig. 5 Velocity-aided prediction model.

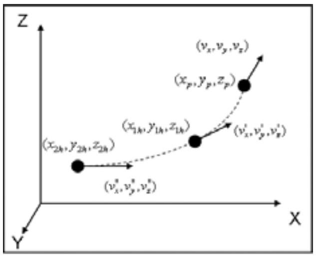


Fig. 6 Constant acceleration prediction model.

$$\begin{cases} v'_x = v''_x + a_x(t_{1h} - t_{2h}) \\ v_x = v'_x + a_x(t_p - t_{1h}) \\ x_p - x_{1h} = \dfrac{(v'_x + v_x)}{2}(t_p - t_{1h}). \end{cases} \tag{14}$$

Then we can get the expected location x_p as

$$x_p = x_{1h} + \frac{2v'_x + (v'_x - v''_x)\frac{t_p - t_{1h}}{t_{1h} - t_{2h}}}{2}(t_p - t_{1h}). \tag{15}$$

Since Y and Z dimensions are the same with X-dimension, therefore finally we have

$$\begin{cases} x_p = x_{1h} + \dfrac{2v'_x + (v'_x - v''_x)\dfrac{t_p - t_{1h}}{t_{1h} - t_{2h}}}{2}(t_p - t_{1h}) \\ y_p = y_{1h} + \dfrac{2v'_y + (v'_y - v''_y)\dfrac{t_p - t_{1h}}{t_{1h} - t_{2h}}}{2}(t_p - t_{1h}) \\ z_p = z_{1h} + \dfrac{2v'_z + (v'_z - v''_z)\dfrac{t_p - t_{1h}}{t_{1h} - t_{2h}}}{2}(t_p - t_{1h}). \end{cases} \tag{16}$$

Based on above models, we can construct predictive and synchronized local views.

3.2 Broadcast Tree Calculation

In our framework, this part is where we make use of existing broadcast algorithms to calculate broadcast tree based on above predicted synchronous local view, that is, to determine the relay instructions and collaboration nodes which should continue broadcast tree calculation work. In principle all kinds of position aware efficient broadcasting protocols can be employed. In those protocols location information facilitates generating a small forward node set and optimal transmission radius, such as incremental power philosophy based BIP [18] and LDBIP [19], broadcast oriented LMST and relative neighborhood graph (RNG) based minimum-energy broadcast protocols [20].

3.3 Broadcast Process

Finally S will include relay instructions and collaboration nodes' id into the packet and send it out. For any node which receives a packet, if the packet includes relay instructions for it, the node will just relay the packet; if the packet includes its id, the node will act as S to construct its own future local view and make successive relay instructions to collaborate completing the broadcast task; if there is no instructions for it, the node can just keep the packet.

Until now, we should have finished the presentation of our framework, however since node S's transmission range is calculated on prediction, the accuracy of prediction will directly determine the effectiveness of our schemes. There are several possible **imprecision factors:**

- GPS reading obtained may not always be accurate due to various reasons (e.g., multi-path fading, indoor conditions, etc.);
- node suddenly changes its direction before future prediction time;
- the movement speed of node can accelerate or decelerate;
- node moves nonlinearly (only for piecewise linear models).

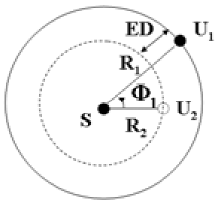


Fig. 7 Sketch map for prediction inaccuracy.

In the real world, these factors cause inaccurate predictions.

After prediction process S achieves its future local view. However because of above imprecise prediction factors it is possible that any neighbor U moves to the position of U_1 while our predicted location is U_2 where R_1 and R_2 respectively represent the distance of U_1 and U_2 to S as shown in Fig. 7. There are two cases:

- $R_2 > R_1$ (1), that is, the predicted location is farther to S than the actual location;
- $R_2 < R_1$ (2), that is, the predicted location is nearer to S than the actual location.

If node S selects R_2 as the transmission radius, in above first case the actual node U can be definitely covered and there will be no problem for delivery ratio. However, in the second case, node U cannot receive packets.

Lengthened Transmission Radius Scheme: In Fig. 7 the prediction error is shown as $ED = (R_1 - R_2)$. If we increase transmission radius by ED, node U can be covered. Therefore to guarantee broadcast coverage, here we propose to use longer transmission radius to start real broadcast process where the transmission radius increment is defined as extra radius (ER). Assume the speed of a node's movement is upper bounded by s and the prediction interval is f, then $\xi = 2sf$ is the maximum value that ED can reach. Therefore, the extra transmission radius (ER) is bonded by ξ.

4. Performance Evaluation

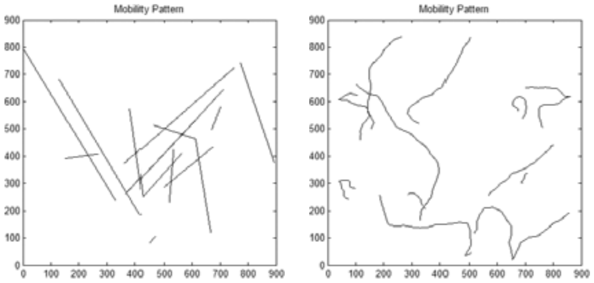
In this section, we evaluate the performance of our generic localized broadcast framework on dealing with the low broadcast coverage problem in mobile ad hoc ubiquitous networks.

4.1 Simulation Environment

We use ns-2.28 [21] and its CMU wireless extension as simulation tool and assume AT&T's Wave LAN PCMCIA card as wireless node model with parameters as listed in Table 1. All simulations are conducted on networks with a practical and widely used IEEE 802.11 MAC layer where contention

Table 1 Parameters for wireless node model.

Parameters	Value
Frequency	2.4 GHz
Maximum transmission range	250 m
Maximum transmit power	0.281838 W
Receiving power	0.395 W
Transmitting power	0.660 W
Omni antenna receiver/transmitter gain	0 dB
MAC protocol	802.11
Propagation model	free space / two ray ground



(a) Random Waypoint model (b) Gauss-Markov model

Fig. 8 Traveling pattern of MNs.

Table 2 Simulation parameters for localized broadcasts.

Parameters	Value
Simulation network size	$900 \times 900\,\mathrm{m}^2$
Nodes number	50/100
Simulation time	150 s
Periodical update/check interval	3 s
Reference distance for conditional update	1 m
Broadcast packet size	64 Bytes
Transmission delay	25 μs
Broadcast traffic rate	10 packets/s
Pause time of Random Waypoint Model	0 s

and collision are simulated. However, a very short (1 ms) forward jitter delay is used for transmission to reduce collisions. The effectiveness of this method has been demonstrated in Wu and Dai's work [11]. We adopt the ideal physical layer model of free space and two ray ground where if a node sends a packet, all neighbors within its transmission range will receive this packet after a very short propagation delay.

To demonstrate the comprehensive effectiveness of our framework, we employ not only linear (Random Waypoint) but also nonlinear (Gauss-Markov) mobility models [17], [22]–[25] which are widely used in simulating protocols. Figure 8 shows the traveling pattern of MNs using above two different kinds of mobility models.

In our simulation network, 50 or 100 nodes are placed in a fixed area ($900 \times 900\,\mathrm{m}^2$) which represents relatively scarce or dense network respectively. Table 2 displays parameters for wireless networks which are used in our simulation.

Table 3 *PE* for various views under Random Waypoint model.

Records Type	Prediction Scheme	*PE* Value
Periodical Update	Update Info Based	7.258410
	Location-based	0.755039
	Velocity-aided	0.003444
	Constant Acceleration	0.261483
Conditional Update	Update Info Based	9.267584
	Velocity-aided	0.000006
	Constant Acceleration	0.637606

Table 4 *PE* for various views under Gauss-Markov model.

Records Type	Prediction Scheme	*PE* Value
Periodical Update	Update Info Based	7.407275
	Location-based	2.281239
	Velocity-aided	0.497334
	Constant Acceleration	1.046533
Conditional Update	Update Info Based	9.497269
	Velocity-aided	1.617758
	Constant Acceleration	2.813394

4.2 Evaluation of Predicted Local View Accuracy

The main idea of our localized framework is to predict the accurate local view for better forward decisions. It is expected that the more accurate the local view is, the better the performance of broadcast protocols is. Therefore first we observe the accuracy of predicted local view based on our prediction models and compare it with that of update information based local view.

To evaluate the accuracy of local view, we define position error (*PE*) metric which is the average distance difference between neighbors' actual positions and their positions in neighborhood view. For any node S suppose there are K neighbors (including S itself) at certain time local view, and for any neighbor i let (x_i, y_i, z_i) represent the actual location and (x'_i, y'_i, z'_i) be the location in local view, then the PE_j for the jth neighborhood can be calculated as

$$\sqrt{\frac{1}{K}\sum_{i=1}^{K}\left[(x'_i - x_i)^2 + (y'_i - y_i)^2 + (z'_i - z_i)^2\right]}. \tag{17}$$

Finally suppose we have W local views,

$$PE = \frac{1}{W}\sum_{j=1}^{W} PE_j. \tag{18}$$

The smaller the value of the *PE* is, the more accurate the neighborhood local view is.

Tables 3 and 4 show position error results under Random Waypoint and Gauss-Markov Models in our simulation. From above results we can find that

- our predicted local view has much smaller prediction inaccuracy compared to that of update information based local view: whatever in periodical or conditional update networks, the *PE* value of update info based local view is more than three times as large as that of our predicted views for the settings used in the simulation;

```
Given an undirected weighted graph $G(N, A)$ where $N$ is
the set of nodes and $A$ is the set of edges
{ /***Initialization***/
  Set $T = \{S\}$ where $S$ is source node of broadcast session;
  Set $W(i) = 0$ for all $1 \le i \le |N|$ where $W(i)$ is the
  transmission power of node $i$.
  While $|T| \ne |N|$
  {/***Tree calculation***/
    Find an edge $(i, j) \in T \times (N - T)$ so that incremental
    power $\Delta W_{ij} = d_{ij}^{\beta} - W(i)$ is minimum ($\beta$ is path loss);
    Add node $j$ to $T$, i.e., $T = T \cup \{j\}$;
    Set $W(i) = W(i) + \Delta W_{ij}$.
  }
}
```

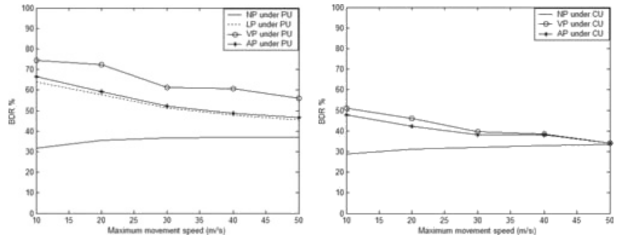
Fig. 9 Pseudo-code of BIP tree construction.

- that is, our predictive schemes can more precisely track nodes' neighborhood views;
- the performance comparison of prediction models can be summarized as follows: velocity-aided scheme performs much better than other two methods and the constant acceleration model does better than location-based one.

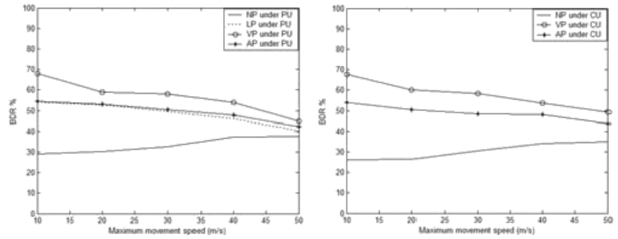
4.3 Evaluation of a Generic Localized Broadcast Framework

We define the *BDR* (Broadcast Delivery Ratio) as *the average percentage of nodes in network that receive broadcasted message for one broadcast task*. To evaluate the effectiveness of our framework in improving broadcast coverage, we observe and compare the *BDR* of existing protocols with that of new algorithms derived from our framework. As for protocols which will be applied to our framework, we choose Broadcast Incremental Power (BIP) [18] since it is well known energy efficient position aware protocol which employs incremental power philosophy and takes advantage of the wireless broadcast advantage. The tree construction of BIP is explained in Fig. 9 where source node calculates broadcast tree by adding nodes one at a time. At each step, the less expensive action to add a node is selected, either by increasing the radius of an already existing emission beam or by creating a new emission beam from a passive one. With the help of our framework, the *BDR* of new algorithm based on BIP is expected to be much higher than that without our framework.

For the convenience of the presentation, in the following sections LBIP is a general name of all localized protocols based on BIP. To differentiate LBIP with and without our framework, NP represents LBIP without our framework and LP represents LBIP based on location-based prediction. Similarly VP is LBIP with velocity-aided prediction and AP is LBIP with constant acceleration prediction. In addition, RWP represents Random Waypoint mobility model, GM represents Gauss-Markov mobility model, PU represents periodical update and CU represents conditional update.

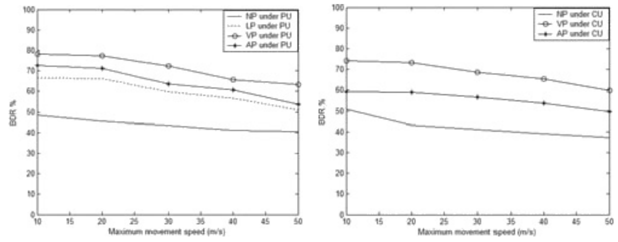


(a) under RWP and PU (b) under RWP and CU

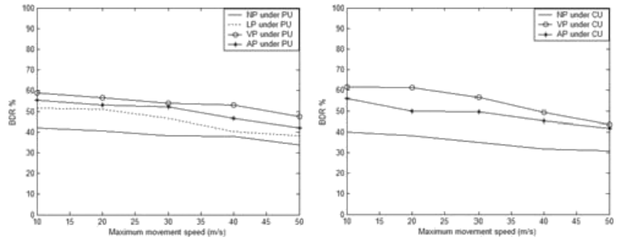


(c) under GM and PU (d) under GM and CU

Fig. 10 The *BDR* of LBIP obtained under various maximum movement speed in relatively scarce networks.



(a) under RWP and PU (b) under RWP and CU



(c) under GM and PU (d) under GM and CU

Fig. 11 The *BDR* of LBIP obtained under various maximum movement speed in relatively dense networks.

In our framework, Lengthened Transmission Radius Scheme (LTR) is a compensation scheme. Therefore we separate our evaluation into two parts without and with LTR.

4.3.1 Evaluation without LTR

Figures 10 and 11 present *BDR* comparison for LBIP in various mobile scenarios under relatively scarce and dense networks respectively. Above figures demonstrate that

- Existing localized protocols suffered very low broadcast coverage in all mobile scenarios. In relatively scarce networks the *BDR* percent of LBIP without our framework (NP) is less than 40 and even in dense networks it also cannot reach to 50.
- Our framework is effective in helping protocols achieve

high broadcast coverage in mobile scenarios. LBIP can achieve much higher *BDR* once applied into our framework. Basically the *BDR* percent is more than 50 and especially in relatively low mobile scenarios it can reach to 70 or 80.

- As the maximum movement speed increases, we have expected that the effectiveness of our predictive framework also decreases. Although the *BDR* of NP in Fig. 10 is increasing because of increasing high *PE* (position error) and many overlapping areas caused by large number of forward nodes of LBIP in relatively scarce networks, however, the *BDR* of LBIP with our framework is still higher than that of NP.
- The performance behavior of our framework according to prediction models can be different. As we have expected, in all mobile scenarios the *BDR* values under various prediction models show $VP > AP > LP$, that is, VP shows the best performance since in the evaluation of predicted local view accuracy in Sect. 4.2, our simulation results have demonstrated that VP can predict the most accurate local view which can lead to the best forward decisions and therefore the best performance in broadcast coverage.
- The type of update protocols and mobility models affect the performance of our framework in broadcast coverage: the *BDR* of LBIP under different update protocols and mobility models are also different.

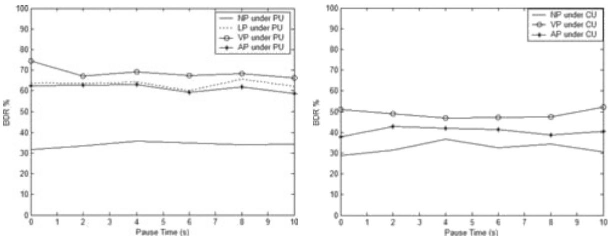
In above simulations, we set the pause time of Random Waypoint mobility model as 0 (s). To observe the effect of pause time on the performance of our scheme, we perform separate simulation which is based on various pause time of RWP model. Simulation results are shown in Figs. 12 and 13. We employ relatively low and high two mobile scenarios where 10 m/s and 50 m/s are maximum movement speed, respectively. In Figs. 12 and 13, as pause time increases, the *BDR* of LBIP basically keeps similar and there is no big difference in all mobile scenarios. This demonstrates that our schemes perform well in general environment whenever mobile terminals pause or not.

From all above analysis we conclude that our schemes can greatly improve the broadcast coverage. However it is less than 80% and still not high enough which is caused by the imprecision of predicted local views. Therefore we proposed LTR to compensate.

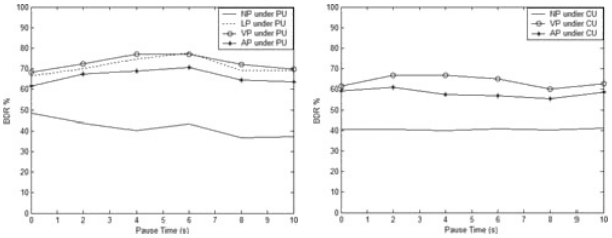
4.3.2 Evaluation with LTR

To evaluate the effectiveness of our framework with LTR, we vary the value of it and observe the *BDR*. Figures 14, 15, 16 and 17 show the *BDR* performance of LBIP under various LTR. Above figures demonstrate that

- Our framework with LTR is more effective than that without it (LTR=0) in helping protocols achieve high broadcast coverage in mobile scenarios. The *BDR* increases greatly as LTR increases. Basically when LTR increases up to 100 m the increment percent range of LBIP is mostly distributed within [20 30]. Consequently the *BDR* of LBIP can even nearly reach to 100%, which demonstrates the effectiveness of our framework.

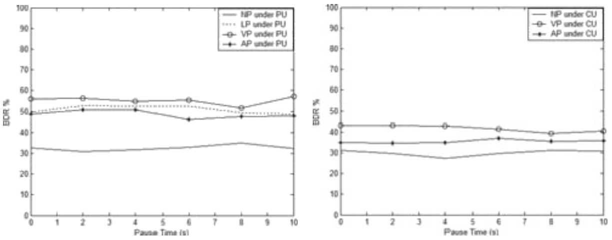


(a) in scarce and PU networks (b) in scarce and CU networks

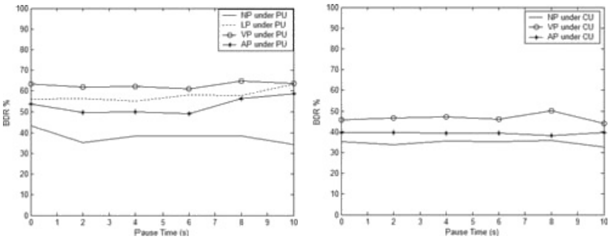


(c) in dense and PU networks (d) in dense and CU networks

Fig. 12 The *BDR* of LBIP obtained under various pause time of Random Waypoint Mobility Model in relatively low mobile scenarios.



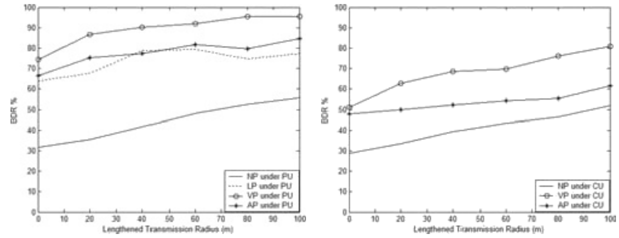
(a) in scarce and PU networks (b) in scarce and CU networks



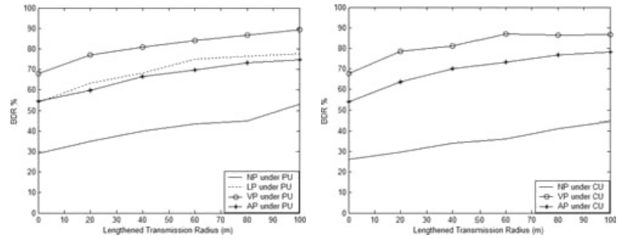
(c) in dense and PU networks (d) in dense and CU networks

Fig. 13 The *BDR* of LBIP obtained under various pause time of Random Waypoint Mobility Model in relatively high mobile scenarios.

- The mobility level of scenario shows great effect on the performance of our framework with LTR in broadcast coverage. In the low mobile scenario the effectiveness of our framework is obvious. Even as LTR increases, the *BDR* of LBIP with our framework is still much higher than that of NP. However, in the high mobile scenario even when other simulation parameters are the same, in linear model and conditional update scenario as shown in Fig. 16(b) and Fig. 17 (b), the *BDR* of NP is already larger than that of AP. We believe that it is because in high mobile scenario the high inaccuracy of

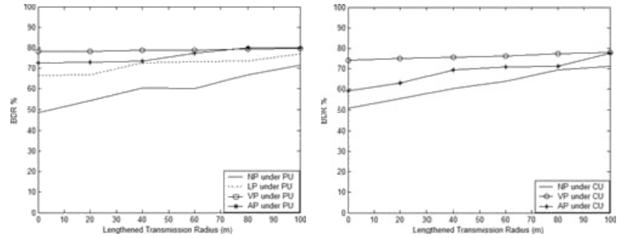


(a) under RWP and PU (b) under RWP and CU

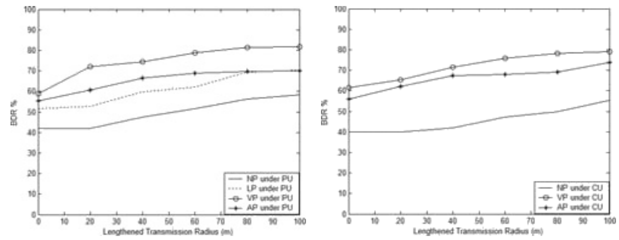


(c) under GM and PU (d) under GM and CU

Fig. 14 The *BDR* of LBIP obtained under various LTR in relatively low mobile and scarce networks.



(a) under RWP and PU (b) under RWP and CU

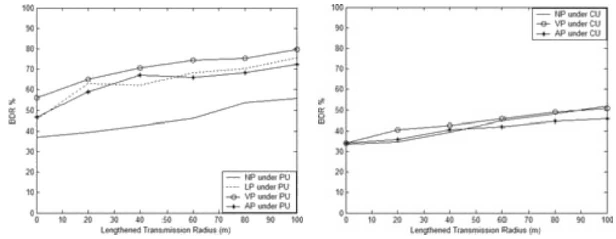


(c) under GM and PU (d) under GM and CU

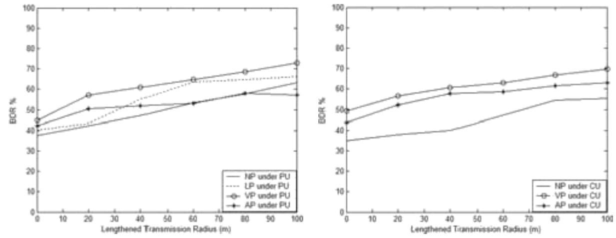
Fig. 15 The *BDR* of LBIP obtained under various LTR in relatively low mobile and dense networks.

local view may lead to the wrong selection for forward nodes which cannot be compensated by LTR.

- The mobility level of scenario also affects the performance of our framework according to different prediction models. In Sect. 4.3.1 we have demonstrated that without LTR the *BDR* value sequence under various prediction models is $VP > AP > LP$. However when we employ the framework with LTR, above sequence is not clear anymore, especially in high mobile scenarios and under periodical update protocols. We believe that the result is caused by the LTR. As LTR increases, the overlapping of transmission also increases which will increase the uncertainty of performance.
- The type of update protocols also affects the performance of our framework in broadcast coverage: the *BDR* of LBIP with LTR under different update protocols are also different.

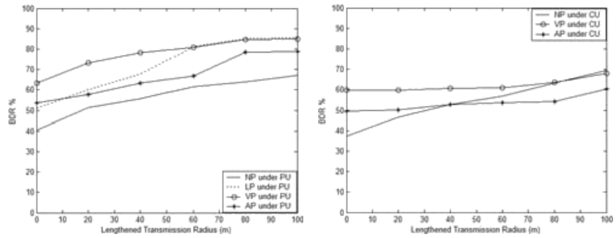


(a) under RWP and PU (b) under RWP and CU

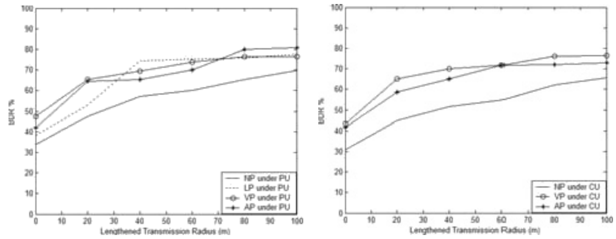


(c) under GM and PU (d) under GM and CU

Fig. 16 The *BDR* of LBIP obtained under various LTR in relatively high mobile and scarce networks.



(a) under RWP and PU (b) under RWP and CU



(c) under GM and PU (d) under GM and CU

Fig. 17 The *BDR* of LBIP obtained under various LTR in relatively high mobile and dense networks.

4.3.3 Discussion

In summary, the performance of our schemes can be summarized and concluded as

- In low and middle mobile scenarios, both our mobility prediction and enhancement LTR schemes are superior to existing update info based framework in terms of broadcast coverage (broadcast delivery ratio).
- Among our three prediction models, basically velocity-based prediction offers the best overall performance.
- However, as mobility increases, the advantage of our

framework is decreasing; in high mobile scenarios, especially in some special scenarios such as linear mobility model and conditional update based scenario, update info based scheme may be superior to our framework.

- Therefore in the future if a designer wants to employ our prediction schemes in application, in low and middle mobile scenarios the designer is highly suggested to employ our schemes; in high mobile scenarios, whether to adopt our schemes or not, depends on the application requirement and designer's preference.
- In addition, the performance may be different according to update protocols; therefore the designer may adjust the type or parameters of update protocols to achieve the performance what he is expecting.

5. Conclusions

In this paper, we have addressed the low broadcast coverage problem caused by outdated and asynchronous local view which exists in existing localized broadcast protocols. We have proposed a generic localized broadcast framework which enables a platform from which new algorithms can be derived from existing protocols and the new algorithms can guarantee high broadcast coverage. This framework includes mobility management, broadcast tree construction and broadcast process. In the broadcast tree construction part existing algorithms are used to calculate broadcast tree. Mobility management focuses on constructing a synchronized local view based on predicted neighbor nodes' future locations which can be employed to make better forward decision to guarantee high broadcast delivery ratio. LTR (lengthened transmission range) is proposed to compensate the prediction inaccuracy. Simulation results show that our generic framework can reform existing algorithms to greatly increase their broadcast coverage.

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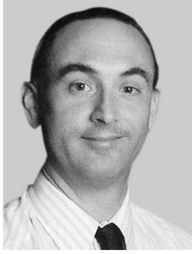
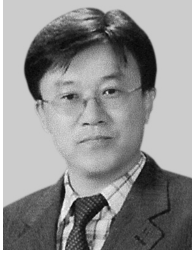
Hui Xu received the B.S. and M.S. degrees in Electrical Instrumentation Engineering from Zhejiang University of China in 2001 and 2004, respectively. Since 2004, she has been pursuing PH.D. degree in Ubiquitous Computing Laboratory of Computer Engineering, Kyung Hee University of Korea. Her research is in Wireless Ad hoc and Sensor Networks area with a focus on the localized broadcasting and topology control protocol design, cross-layer design of realistic physical layer effect on the network layer protocol, and mobility management to improve protocols performance in reliability.



Brian J. d'Auriol received the B.Sc. (CS) and Ph.D. degrees from the University of New Brunswick in 1988 and 1995, respectively. He joined Kyung Hee University, Korea, in 2006 as a research faculty. Previously, he had been a researcher at the Ohio Supercomputer Center, USA and assistant professor at several American and Canadian universities. He has organized International Conference on Communications in Computing 2000–2008 and the 11th Annual International Symposium on High Performance Computing Systems. His research includes data visualization, optical-communication parallel computing models, communication and computation modeling, and ubiquitous sensor networks. He is a member of the ACM and IEEE.

Jinsung Cho received his B.S. degree in computer engineering from Seoul National University, Korea in 1983, M.S. degree in computer science from the Korea Advanced Institute of Science and Technology, Korea in 1985 and Ph.D. degree in computer science from Georgia Institute of Technology, Atlanta, USA in 1995. In 1996, he joined Kyung Hee University, Korea. He is now an associate professor at the College of Electronics & Information at Kyung Hee University. From 1985 to 1989, He was a research staff at the Data Communications Corp., Korea. From 2003 to 2004, he was a visiting scholar at Georgia Institute of Technology, Atlanta. His research interests include database systems, data mining, and mobile computing.

Sungyoung Lee received his B.S. from Korea University, Seoul, Korea. He got his M.S. and Ph.D. degrees in Computer Science from Illinois Institute of Technology (IIT), Chicago, Illinois, USA in 1987 and 1991 respectively. He has been a professor in the Department of Computer Engineering, Kyung Hee University, Korea since 1993. He is a founding director of the Ubiquitous Computing Laboratory, and has been affiliated with a director of Neo Medical ubiquitous-Life Care Information Technology Research Center, Kyung Hee University since 2006. Before joining Kyung Hee University, he was an assistant professor in the Department of Computer Science, Governors State University, Illinois, USA from 1992 to 1993. His current research focuses on Ubiquitous Computing and applications, Context-aware Middleware, Sensor Operating Systems, Real-Time Systems and Embedded Systems. He is a member of the ACM and IEEE.



Byeong-Soo Jeong received his B.S. degree in computer engineering from Seoul National University, Korea in 1983, M.S. degree in computer science from the Korea Advanced Institute of Science and Technology, Korea in 1985 and Ph.D. degree in computer science from Georgia Institute of Technology, Atlanta, USA in 1995. In 1996, he joined Kyung Hee University, Korea. He is now an associate professor at the College of Electronics & Information at Kyung Hee University. From 1985 to 1989, He was a research staff at the Data Communications Corp., Korea. From 2003 to 2004, he was a visiting scholar at Georgia Institute of Technology, Atlanta. His research interests include database systems, data mining, and mobile computing.