Kinetic Multipoint Relaying: Improvements Using Mobility Predictions*

Jérôme Härri, Fethi Filali, and Christian Bonnet

Institut Eurécom**
Department of Mobile Communication
B.P. 193
06904 Sophia-Antipolis, France
{Jerome.Haerri,Fethi.Filali,Christian.Bonnet}@eurecom.fr

Abstract. Multipoint Relaying (MPR) is a technique to reduce the number of redundant retransmissions while diffusing a broadcast message in the network, where only a subset of nodes are allowed to forward packets. The selection is based on instantaneous nodes' degrees, and is periodically refreshed. We propose in this chapter a novel heuristic to select kinetic multipoint relays based on nodes' overall predicted degree, which is solely updated on a per-event basis. We illustrate that this approach significantly reduces the number of messages needed to operate the protocol, yet with similar broadcast properties that the regular MPR, such as network coverage, number of multipoint relays, or flooding capacity.

1 Introduction

Multipoint relaying (MPR, [1]) provide a localized way of flooding reduction in a mobile ad hoc network. Using 2-hops neighborhood information, each node determines a small set of forward neighbors for message relaying, which avoids multiple retransmissions and blind flooding. MPR has been designed to be part of the Optimized Link State Routing algorithm (OLSR, [2]) to specifically reduce the flooding of TC messages sent by OLSR to create optimal routes. Yet, the election criteria is solely based on instantaneous nodes' degrees. The network global state is then kept coherent through periodic exchanges of messages. Some studies showed the impact of periodic beacons on the probability of transmission in 802.11, or on the battery life [4,3]. This denotes that these approaches have major drawbacks in terms of reliability, scalability and energy consumptions. The next step to their evolution should therefore be designed to improve the channel occupation and the energy consumption.

In this chapter, we propose to improve the MPR protocol by using mobility predictions. We introduce the *Kinetic Multipoint Relaying (KMPR)* protocol, which heuristic selects kinetic relays based on nodes actual and future predicted nodal degrees. Based

* An extended version of this chapter is available as a technical report under the reference RR_05_148 at http://www.eurecom.fr/people/haerri.en.htm

** Institut Eurécom's research is partially supported by its industrial members: Bouygues Télécom, France Télécom, Hitachi Europe, SFR, Sharp, ST Microelectronics, Swisscom, Texas Instruments, Thales.

D. Hutchison et al. (Eds.): IWAN 2005, LNCS 4388, pp. 224–229, 2009.

on this, periodic topology maintenance may be limited to the instant when a change in the neighborhood actually occurs. Our objective is to show that this approach is able to significantly reduce the number of messages needed to maintain the backbone's consistency, thus saving network resources, yet with similar flooding properties as the regular MPR.

The rest of the chapter is organized as follows. Section 2 describes the heuristic to compute kinetic degrees. Then, in Section 3, we describe the KMPR protocol. Finally, Section 4 provides simulation results, while Section 5 draws some concluding remarks.

2 Kinetic Nodal Degree in MANETs

We explain in this section the method for modeling kinetic degrees in MANETs. We model nodes' positions as a piece-wise linear trajectory and, as shown in [5], the corresponding trajectory durations are lengthy enough to become a valuable cost for using kinetic degrees.

Over a relatively short period of time[1], one can assume that each such node, say i, follows a linear trajectory. Its position as a function of time is then described by

$$\mathbf{Pos}_i(t) = \begin{bmatrix} x_i + dx_i & \cdot & t \\ y_i + dy_i & \cdot & t \end{bmatrix},$$

where $Pos_i(t)$ represents the position of node i at time t, the vector $[x_i,\ y_i]^T$ denotes the initial position of node i, and vector $[dx_i,\ dy_i]^T$ its initial instantaneous velocity. Let us consider node j as a neighbor of i. The squared distance between nodes i and j is defined as

$$\begin{aligned} D_{ij}^2(t) = D_{ji}^2(t) &= \|\mathbf{Pos}_j(t) - \mathbf{Pos}_i(t)\|_2^2 \\ &= \left(\begin{bmatrix} x_j - x_i \\ y_j - y_i \end{bmatrix} + \begin{bmatrix} dx_j - dx_i \\ dy_j - dy_i \end{bmatrix} \cdot t \right)^2 \\ &= a_{ij}t^2 + b_{ij}t + c_{ij}, \end{aligned}$$

Considering r as nodes maximum transmission range, as long as $D_{ij}^2(t) \leq r^2$, nodes i and j are neighbors. Therefore, solving

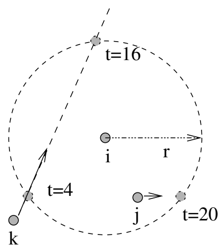
$$D_{ij}^2(t) - r^2 = 0$$

gives t_{ij}^{from} and t_{ij}^{to} as the time intervals during which nodes i and j remain neighbors. Consequently, we can model nodes' kinetic degree as two successive sigmoid functions, where the first one jumps to one when a node enters another node's neighborhood, and the second one drops to zero when that node effectively leaves that neighborhood.

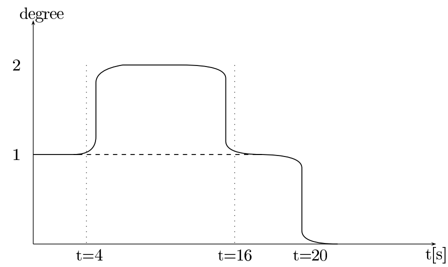
Considering $nbrs_i$ as the total number of neighbors detected in node i's neighborhood at time t, we define

$$Deg_i(t) = \sum_{k=0}^{nbrs_i} \left(\frac{1}{1 + \exp(-a \cdot (t - t_k^{from}))} \cdot \frac{1}{1 + \exp(a \cdot (t - t_k^{to}))} \right) \tag{1}$$

[1] The time required to transmit a data packet is orders of magnitude shorter than the time the node is moving along a fixed trajectory.



(a) Node i kinetic neighborhood



(b) Node i kinetic nodal degree

Fig. 1. Illustration of nodes kinetic degrees

as node i's kinetic degree function, where t_k^{from} and t_k^{to} represent respectively the time a node k enters and leaves i's neighborhood. Thanks to (1), each node is able to predict its actual and future degree and thus is able to proactively adapt its coverage capacity. Fig. 1(a) illustrates the situation for three nodes. Node k enters i's neighborhood at time $t = 4s$ and leave it at time $t = 16s$. Meanwhile, node j leaves i's neighborhood at time $t = 20s$. Consequently, Fig. 1(b) illustrates the evolution of the kinetic degree function over t.

Finally, the kinetic degree is obtained by integrating (1)

$$\widehat{Deg}_i(t) = \int_t^{\infty} \left(\sum_{k=0}^{k=nbrs_i} \left(\frac{1}{1+\exp(-a \cdot (t - t_k^{from}))} \cdot \frac{1}{1+\exp(a \cdot (t - t_k^{to}))} \right) \right) \quad (2)$$

For example, in Fig. 1(b), node i kinetic degree is ≈ 32.

3 Kinetic Multipoint Relays

In this section, we describe our Kinetic Multipoint Relaying protocol. It is mainly extracted from the regular MPR protocol. Yet, we adapt it to deal with kinetic degrees.

To select the kinetic multipoint relays for node i, let us call the set of 1-hop neighbors of node i as $N(i)$, and the set of its 2-hops neighbors as $N^2(i)$. We first start by giving some definitions.

Definition 1 (Covering Interval). *The covering interval is a time interval during which a node in $N^2(i)$ is covered by a node in $N(i)$. Each node in $N^2(i)$ has a covering interval per node i, which is initially equal to the connection interval between its covering node in $N(i)$ and node i. Then, each time a node in $N^2(i)$ is covered by a node in $N(i)$ during some time interval, this covering interval is properly reduced. When the covering interval is reduced to $\emptyset$, we say that the node is fully covered.*

Definition 2 (Logical Kinetic Degree). *The logical kinetic degree is the nodal degree obtained with (2) but considering covering intervals instead of connection intervals. In that case, t_k^{from} and t_k^{to} will then represent the time interval during which a node $k \in N^2(i)$ starts and stops being covered by some node in $N(i)$.*

The basic difference between MPR and KMPR is that unlike MPR, KMPR does not work on time instants but on time intervals. Therefore, a node is not periodically elected, but is instead designated KMPR for a time interval. During this interval, we say that the KMPR node is active and the time interval is called its activation.

The KMPR protocol elects a node as KMPR a node in $N(i)$ with the largest logical kinetic degree. The activation of this KMPR node is the largest covering interval of its nodes in $N^2(i)$.

Kinetic Multipoint Relaying (KMPR)
The KMPR protocol applied to an initiator node i is defined as follows:

- Begin with an empty KMPR set.
- First Step: Compute the logical kinetic degree of each node in $N(i)$.
- Second Step: Add in the KMPR set the node in $N(i)$ that has the maximum logical kinetic degree. Compute the activation of the KMPR node as the maximum covering interval this node can provide. Update all other covering intervals of nodes in $N^2(i)$ considering the activation of the elected KMPR, then recompute all logical kinetic degrees. Finally, repeat this step until all nodes in $N^2(i)$ are fully covered.

Then, each node having elected a node KMPR for some activations is then a KMPR Selector during the same activation. Finally, *KMPR flooding* is defines as follows:

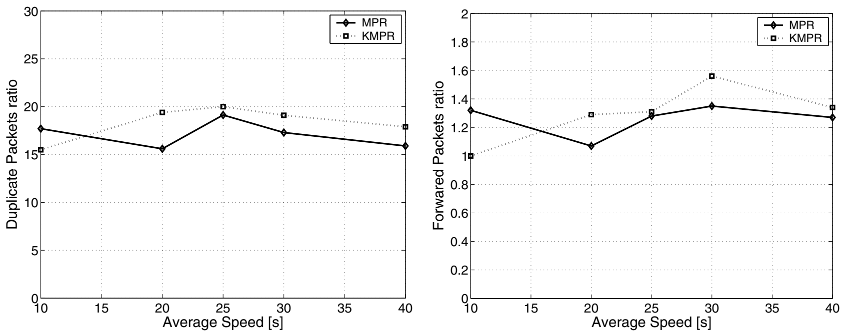
Definition 3 (KMPR flooding). *A node retransmits a packet only once after having received the packet the first time from an active KMPR selector.*

4 Simulation Results

We implemented the KMPR protocol under ns-2 and used the NRL MPR [7] implementation for comparison with KMPR. We measured several significant metrics for Manets: The effectiveness of flooding reduction, the delay before the network receives a broadcast packet, the number of duplicate packets and finally the routing overhead. The following metrics were obtained after the population of 20 nodes were uniformly distributed in a 1500×300 grid. Each node has a transmission range of $250m$. The mobility model we used is the standard Random Mobility Model where we made nodes average velocity vary from $5m/s$ to $30m/s$. Finally, we simulated the system for $100s$.

Figure 2 illustrates the flooding reduction of MPR and KMPR. Although MPR is slightly more performing than KMPR, we can see that both protocols are close together and have a fairly good flooding reduction, both in terms of duplicate and forwarded packets. Note that the low fraction of relays in Fig 2(b) comes from the rectangular topology, where only a couple of MPRs are used as bridge in the center of the rectangle.

On Fig. 3, we depicted the broadcast efficiency of MPR and KMPR. In the simulations we performed, we measured the broadcast efficiency as the time a packet takes before being correctly delivered to the entire network. As we can see, KMPR has a delivery time faster than MPR by 50%. This might comes from two properties of KMPR. Firstly, as described in [6], MPR suffers from message decoding issues, which we corrected in KMPR. Secondly, as we will see in the next figure, KMPR's backbone maintenance is significantly less than MPR. Therefore, the channel access is faster and the probability of collisions is decreased.



(a) Duplicate reception (b) Forwarding Nodes

Fig. 2. Illustration of the flooding reduction of MPR and KMPR

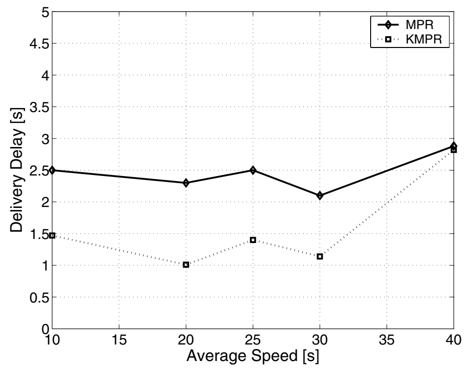
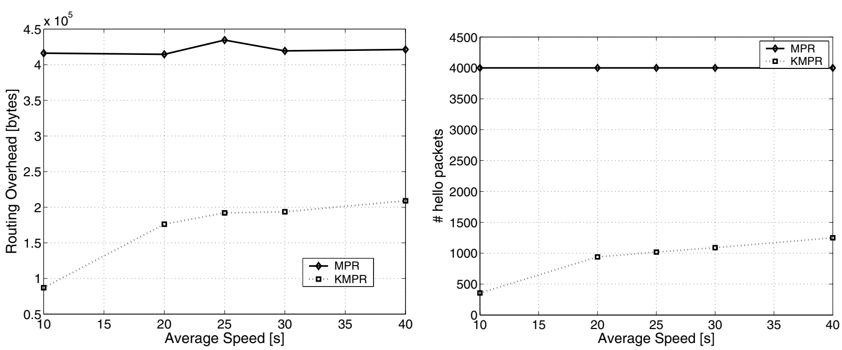


Fig. 3. Illustration of the broadcast efficiency of MPR and KMPR



(a) Routing overhead (b) Number of Hello packets

Fig. 4. Illustration of the network load for MPR and KMPR

In the two previous figures, we have shown that KMPR had similar properties than MPR in term of flooding reduction and delay. Now, in Fig. 4, we illustrate the principal benefit of KMPR: its *low routing overhead*. Indeed, by using mobility predictions, the routing overhead may be reduced by 75% as it may be seen on Fig. 4(a). We also show on Fig. 4(b) the number of hello messages which drops dramatically with KMPR, yet still preserving the network's consistency.

5 Conclusions

In this chapter, we presented a original approach for improving the well-known MPR protocol by using mobility predictions. We showed that the Kinetic Multipoint Relaying (KMPR) protocol was able to meet the flooding properties of MPR, and this by reducing the MPR channel access by 75% and MPR broadcast delay by 50%. We consequently illustrated that, after having been studied in other fields of mobile ad hoc networking, mobility predictions are also an interesting technique to improve broadcasting protocols.

References

1. Laouiti, A., et al.: Multipoint Relaying: An Efficient Technique for Flooding in Mobile Wireless Networks. In: 35th Annual Hawaii International Conference on System Sciences (HICSS 2001), Hawaii, USA (2001)
2. Clausen, T., Jacquet, P.: Optimized Link State Routing Protocol (OLSR), Project Hipercom, INRIA, France (October 2003), www.ietf.org/rfc/rfc3626.txt
3. Bianchi, G.: Performance analysis of the IEEE 802.11 distributed coordination function. IEEE Journal on Selected Areas in Communications 18(3), 535–547 (2000)
4. Toh, C.-K., Cobb, H., Scott, D.A.: Performance evaluation of battery-life-aware routing schemes for wireless ad hoc networks. In: 2001 IEEE International Conference on Communications (ICC 2001), June 2001, vol. 9, pp. 2824–2829 (2001)
5. Haerri, J., Bonnet, C.: A Lower Bound for Vehicles Trajectory Duration. In: IEEE VTC Fall 2005, Dallas, USA (September 2005)
6. Haerri, J., Bonnet, C., Filali, F.: OLSR and MPR: Mutual Dependences and Performances. In: Proc. of the 2005 IFIP Med-Hoc-Net Conference, Porquerolles, France (June 2005)
7. NRLOLSR, http://pf.itd.nrl.navy.mil/projects.php?name=olsr