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The Distribution of Route Search Packet Flows in *Ad Hoc* Networks

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Introduction

A mobile Ad Hoc network consists of mobile nodes that self-organize into a network and communicate via wireless links as hosts sending and receiving data packets and as routers performing user data packet routing. Separate mobile Ad Hoc networks are connected to a hierarchical structure, thus forming a wireless mesh network, consisting of mobile nodes and stationary wireless mesh routers [1]. The individual route is being established between two network nodes before data transfer, however it changes frequently because of network mobility. The routing process consists of a number of steps in which route search (RS) packets are being sent. RS packet generally consists of the following data: the IP addresses and location data of source and destination nodes, sequence number and the unique identification number. In case of network with many nodes there is a large amount of RS packets. Specialized routing protocols are used in Ad Hoc networks that generate relatively smaller amount of RS packets [2].

The core part of every routing protocol is the routing algorithm, which specifies all the logical processes of routing. Various routing algorithms for Ad Hoc networks do not change the response zones as network topology varies and do not guarantee the smallest possible number of RS packets [2]. Response zone of a node is a space, where nodes forward received RS packets further to the network. In this way, new response zones are formed at every next step of the routing process.

Flooding is a routing method in which received RS packet is sent through every outgoing link without the initial information about network topology (Fig. 1).

Greedy routing is a routing method in which RS packets are sent through the single node that is closest to the destination node in each RS step. The distances between the nodes are calculated by using node location data.

The objective of the research is to determine the dependences of RS packet flow parameters on the density of network nodes for different flooding-based and greedy routing algorithms.

Algorithms for reducing the amount of RS packets

The number of RS steps depends on the amount of transit nodes along the direction from source node M_s to the destination node M_d. In a randomly changing network topology the amount of transit nodes is a random variable.

Each node has its radio coverage area with radius R. The number of nodes N within the radio coverage area of each node defines the network density. The amount of RS packets generated at the routing step n is

$$a_n = N^n, \tag{1}$$

where a_0 – the initial number of RS packets ($a_0=1$). The amount of RS packets sent from $n=0$ to n steps of the route search process is

$$S_n = a_0 + \sum_{k=1}^{n} N^k . \tag{2}$$

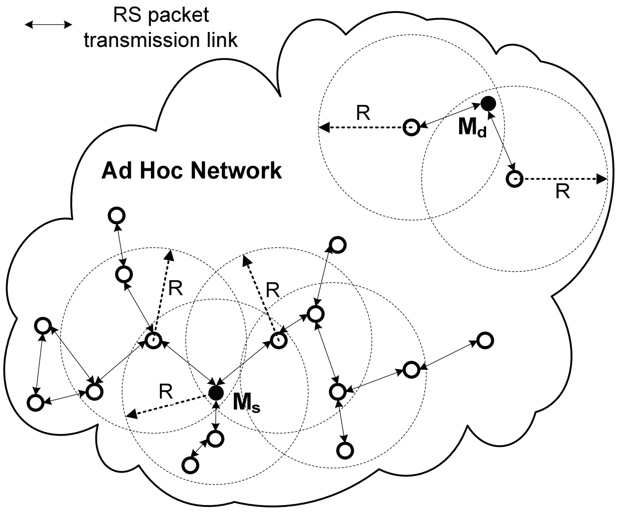

Fig. 1. Flooding the Ad Hoc network with RS packets

The amount of RS packets can be reduced by using the radio signal strength and location data of nodes. As network topology varies, it is appropriate to evaluate one of these parameters at each routing step, or combine them both for dynamic control of response zones (Fig. 2.).

For location-based routing each node has to know the current locations of all other nodes. Location-aided routing (LAR) [3] is a restricted flooding protocol that consists of two algorithms. LAR-1 algorithm operates by flooding a rectangular network part with *route request* (*Rreq*) packets, where source node M_s and destination node M_d are at the corners of the rectangle. In LAR-2 case *Rreq* packets are forwarded by the nodes that are closer to the destination M_d than the node from which they received the *Rreq* packet. No-Beacon Geographic Direction (NB-GEDIR) [4] algorithm performs greedy routing – the single node with minimum distance to the destination M_d is elected to be the route next-hop node out of a set of neighbour nodes, that have sent their coordinates to the requesting node in *location reply* (*Lrep*) packets after receiving the *location request* (*Lreq*) packet.

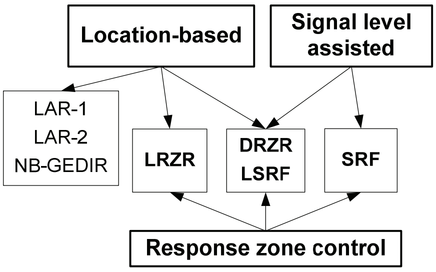

Fig. 2. The classification of routing algorithms for reducing the amount of RS packets

The Limited Response Zone Routing (LRZR) [5] algorithm operates by applying the response zone limiting radius r inside the radio coverage area with radius R in order to decrease the amount of RS packets. Therefore, the response zone of the current node M is a planar shape – sector of the ring, defined by the coordinates of source node M_s and destination node M_d, as well as radii R, r, and $\rho(M\,M_d)$ [5].

The signal strength values are used in the location-based greedy Dynamic Response Zone Routing (DRZR) [6] algorithm to avoid routing to the nodes with low quality radio links. Instead of using the response zone limiting radius r (as in LRZR), the response zone is set by applying the signal strength range $[S_M; s_M]$, where $S_{min} \le S_M \le s_M$ and M is the current node. S_{min} is the marginal signal strength value, corresponding to the radio coverage area boundary, i.e. the lowest signal strength possible for successful radio communication. The signal strength values of the range are set according to the formula

$$s_i(d) = P - L(d), \tag{3}$$

where s_i – the signal level at the distance d from the current node; P is the transmitting signal power of the current node (in dBm), $L(d)$ is a path loss (in dB) for a particular distance d in free space according to the Free-space path loss model [7].

The Signal level Restricted Flooding (SRF) [8] routing algorithm performs flooding of *Rreq* packets in restricted response zones that are specified by signal strength range, as in DRZR algorithm. Location data is not used in SRF, so *Rreq* packets are disseminated in all network directions. By exploiting node location data for restricted flooding, the Location-based Signal level Restricted Flooding (LSRF) routing algorithm has been created, which is the extension of the SRF algorithm.

As SRF and LSRF perform restricted flooding there is no single node elected to be the next-hop node during the RS process. The dissemination of *Rreq* packets is performed without the intervention of the sending node. Therefore, *Rreq* packet cannot be retransmitted in case of an empty response zone. Instead, the nodes outside the response zone set a timer $t=T$ after the receipt of *Rreq* packet with a random value T and listen for *Rreq* packets being sent. When $t=0$, if there weren't any nodes sending *Rreq* packets, the response zone is considered to be empty, so the current node disobeys the response zone limitation and forwards the *Rreq* packet.

The simulations of RS packet flows

The operation of flooding-based (AODV), location-based (LAR-1, NB-GEDIR), and response zone controlling (DRZR, SRF, LSRF) routing algorithms has been implemented in Matlab environment. The amount of RS packets has been evaluated on the network model, where nodes are arranged in a regular square structure with distances among adjacent nodes in perpendicular directions equal to U. The model is defined by the matrix $T = [t_{ij}]$, $i = \overline{1,I}$, $j = \overline{1,J}$, where $W = I \cdot J$ is a total number of nodes in the network. The node is active if an appropriate matrix element is $t_{ij} = 1$ [5].

The variable network topology is simulated by randomly disabling required matrix elements (setting to $t_{ij}=0$). This network model can be also used for analysing the characteristics of data packet transmissions over the unreliable channels in a multi-route environment [9].

It is considered that network topology does not change during the single route search. RS packets can disseminate freely inside the network in all directions depending on the routing algorithm being used.

In case of a widely used Ad-Hoc On Demand Distance Vector (AODV) routing algorithm [10] each node sends the *Rreq* packet only once during the single route search. Therefore, even though location data and signal strength parameters are not used in AODV, the amount of RS packets generated at the routing step n is

$$a_n = a_1 + D(n-1), \tag{4}$$

where a_1 – the number of RS packets generated at the first step of the routing process, $D = a_n - a_{n-1}$, $n=2,3,4\ldots$ The amount of RS packets from $n=1$ to n steps of the RS process is

$$S_n = a_0 + n\frac{2a_1 + D(n-1)}{2}. \tag{5}$$

The dependence of RS packet amount on Ad Hoc network density N is presented in Fig. 3. The results indicate that the denser the network, the larger the amount of RS packets is generated.

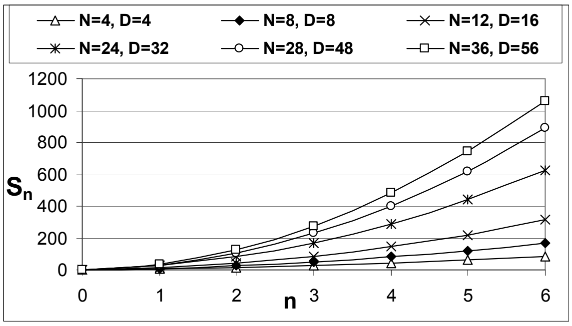

Fig. 3. The dependence of RS packet amount on Ad Hoc network density

The response zone for DRZR, SRF and LSRF routing algorithms is set by applying the signal strength range $[S_M; s_M]$ according to (3): $S_M = S_{\min} = P - L(R)$ and $s_M = P - L(R/2)$.

The distribution of RS packets generated by different routing algorithms in low density network (*N=8*) and high density network (*N*=36) are presented in Fig. 4 and Fig. 5.

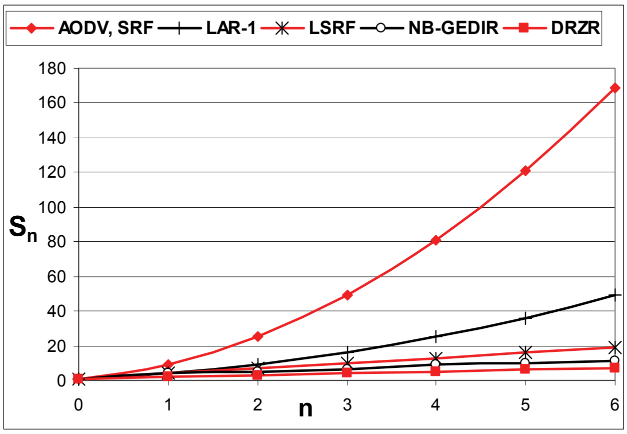

Fig. 4. The distribution of RS packets in low density network (*N*=8)

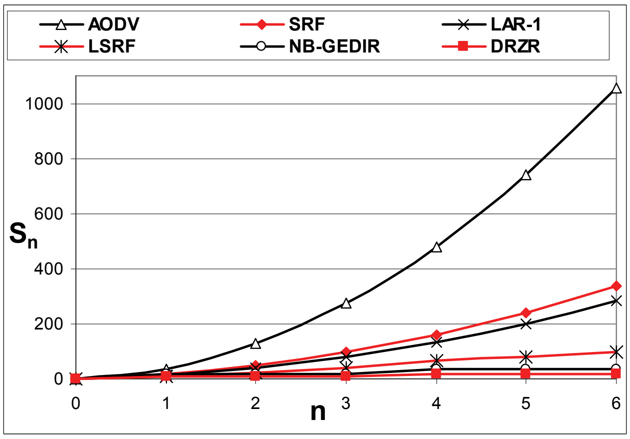

Fig. 5. The distribution of RS packets in high density network (*N*=36)

As NB-GEDIR and DRZR algorithms perform greedy routing, the number of new RS packets generated at the step *n* of the RS process is expressed by a discrete function

$$a_n = \begin{cases} Z, \ if \ n = 1 + 3(m-1), \ \ where \quad m = \overline{1,n}\,, \\ 1, \ if \ \ otherwise\,, \end{cases} \tag{6}$$

where *Z* – the amount of RS packets in the restricted response zone, *n=1,2,3….* a_0 = 1, because the source node M_s generates a single *Lreq* packet. The amount of RS packets sent during the RS process is

$$S_n = S_{n-1} + a_n\,. \tag{7}$$

According to the simulation results from Fig. 4 and Fig. 5, the parameters *Z* and *D* have been determined for flooding-based routing algorithms (Table 1). Greedy routing does not perform according the arithmetic progression, so *D* values are not available.

Table 1. The distribution parameters of RS packets

Routing algorithms	Low density network (N=8)			High density network (N=36)		
	a_1	D	Z	a_1	D	Z
AODV	8	8		36	56	
SRF	8	8		28	32	
LAR-1	3	2		12	14	
LSRF	3	0		13	8	
NB-GEDIR			3			16
DRZR			3			11

In all cases of simulation AODV routing algorithm generates the biggest amount of RS packets, as it performs flooding on the entire network. The number of generated *Rreq* packets during a single RS is equal to the total number of nodes; therefore every node forwards one *Rreq* packet. The amount of *Rreq* packets generated in the first step of the routing process is $a_1 = N$, as the response zone is not reduced and coincides with the radio coverage area. The amount of RS packets increases significantly especially in high density networks, so it is not reasonable to use AODV algorithm in networks with large number of nodes. However, flooding always finds the route, if it exists in the network. Greedy routing can result in RS failure, if there is no any node closer to the destination node M_d than the node sending the *Lreq* packet.

Fig. 4 and Table 1 results indicate that location-based routing (Fig. 2) is the most effective method to reduce the amount of RS packets in low density network. Response zone restrictions in SRF give no effect comparing with AODV flooding, because there are no nodes outside the response zone that would be excluded from routing. NB-GEDIR and DRZR algorithms perform best considering the amount of RS packets as the dissemination of RS packets is constant. As for SRF, response zone restrictions with signal strength range by using DRZR algorithm give no reduction in amount of RS packets when comparing with NB-GEDIR algorithm.

Fig. 5 and Table 1 simulation results for high density network indicate that response zone restrictions with signal strength range in SRF algorithm give the reduction of the value *D* by 1.75 times comparing with AODV flooding, as well as LSRF comparing with LAR-1. The use of location data in LRSF allows reducing the *D* value about 4 times comparing with SRF algorithm. DRZR routing algorithm reduces the response zone size by about 1.45 times comparing with NB-GEDIR algorithm.

When applying response zone restrictions by signal strength range, the size of the response zone depends on the width of the ring or its sector that has been initially set. However, setting the thinner response zone could result in failure of getting *Lrep* packets especially in low density networks.

Conclusions

The route search packets are generated in the network during the routing process. When the entire network is flooded with route search packets, the amount of generated route search packets grows according to the geometric progression, as every node sends route search packets. It is required to reduce the amount of route search packets by restricting the network flooding.

The amount of route search packets can be reduced by using node location data, signal strength levels and dynamic control of response zones. When using these parameters the number of route search packets generated at every routing step increases according to the arithmetic progression or may be constant.

The operation of flooding-based, location-based and signal level assisted routing algorithms has been implemented in Matlab environment. The simulations of routing algorithms have been performed on low density and high density network model in order to get the distribution parameters of route search packet flows.

The simulation results indicate that location-based DRZR routing algorithm with signal strength assisted response zone restrictions operates by generating the smaller amount of route search packets. The reduction of the number of route search packets is especially significant in high density networks. In low density networks the location-based flooding (LAR, LSRF algorithms) should be used, as signal strength assisted response zone restrictions do not reduce the amount of route search packets and can result in routing into an empty response zone.

Acknowledgement

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The amount of route search (RS) packets in Ad Hoc networks depend on the usage of network node location data and signal strength levels for defining response zones and sending RS packets. In case when route response zones are not restricted in every next step of the routing process, the number of generated RS packets grows according to the geometric progression. When node location data and signal strength level is used, the number of RS packets generated at the next routing step increases according to the arithmetic progression or may be constant. It has been shown in the paper that response zone restrictions help to reduce the number of generated RS packets significantly in high density network, while exploiting the location data and signal strength level in lower density network is less efficient. Ill. 5, bibl. 10, tabl. 1 (in English; abstracts in English and Lithuanian).

R. Plėštys, R. Zakarevičius. Maršrutų paieškos paketų plitimo dėsningumai *Ad Hoc* tipo tinkluose // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2011. – Nr. 9(115). – P. 33–36.

Maršrutų paieškos paketų srautai *Ad Hoc* tipo tinkluose priklauso nuo turimos informacijos apie tinklo mazgų vietas ir signalo lygius panaudojimo formuojant atsako zonas ir išsiunčiant užklausų paketus. Neribojant maršrutų atsako zonų kiekviename tolesniame žingsnyje generuojamų paketų skaičius didėja geometrine progresija. Naudojant tinklo mazgų vietos ir radijo signalo lygių duomenis, kiekviename maršruto paieškos žingsnyje generuojamų paketų skaičius kinta aritmetine progresija arba gali būti pastovus. Parodyta, kad didelio mazgų tankio tinkluose tai leidžia gerokai sumažinti generuojamų maršrutų paieškos paketų skaičių, o mažo mazgų tankio tinkluose vietos informacija ir signalo lygis naudojami ne taip efektyviai. Il. 5, bibl. 10, lent. 1 (anglų kalba; santraukos anglų ir lietuvių k.).