Stopping ongoing broadcasts in large MANETs

Rui Lima [*]
Universidade Lusíada
CLEGI
V. N. Famalicão, Portugal
rml[at]fam.ulusiada.pt

Carlos Baquero
Universidade do Minho
HASLab / INESC tec
Braga, Portugal
cbm[at]di.uminho.pt

Hugo Miranda [†]
Universidade de Lisboa
LaSIGE
Lisboa, Portugal
hmiranda[at]di.fc.ul.pt

ABSTRACT

Broadcast is a communication primitive building block widely used in mobile ad-hoc networks (MANETs) for the exchange of control packets and resource location for upper level services such as routing and management protocols. Flooding is the most simple broadcast algorithm, but it wastes a lot of energy and bandwidth, as flooding leads to many redundant radio transmissions. An optimization to flooding is to contain it, once the resource has been found. In this paper, we compare the impact on the latency and power consumption of four competing approaches for flooding containment. The results show that stopping ongoing broadcasts can achieve promising performance increases over other flooding base techniques, when applied in large scale MANETs with scarce power resources. In addition, results show that both network topology and the number of copies of the resource influence differently the performance of each searching approach.

Categories and Subject Descriptors

C.2.2 [**Computer-Communication Networks**]: Network Protocols; C.4 [**Computer-Communication Networks**]: Performance of Systems—*Reliability, Availability, and Serviceability*

General Terms

Experimentation, Protocols, Performance, Resilience

Keywords

Multi-hop Wireless Networks, Mobile Systems, Searching Protocols, Broadcast, Availability

[*]The work reported in this paper was co-financed by FCT - Fundação para a Ciência e Tecnologia, Portugal (PEst-OE/EME/UI4005/2011) and carried out within the research centre Centro Lusíada de Investigação e Desenvolvimento em Engenharia e Gestão Industrial (CLEGI).

[†]Author was partially supported by Fundação para a Ciência e Tecnologia (FCT) through project PTDC/EIA-EIA/103751/2008 - PATI

ARMOR '12 May 08-11 2012, Sibiu, Romania

1. INTRODUCTION

The number of mobile devices available to assist human activities in everyday life is already quite expressive and is easily predicted to continue increasing. Ubiquitous environments, with embedded wireless mobile devices, require large amounts of data to be exchanged and communication is expected to be increasingly supported by mobile ad hoc networks (MANETs). In MANETs the network topology changes frequently. Therefore, any collected global knowledge of the network is quickly outdated. Device mobility creates several communication problems and some of the well known solutions for route discovery, resource query or data dissemination cannot be directed applied [3]. Usually, the solutions for the previous communications problems rely on broadcasting mechanisms. Broadcasting mechanisms are used in MANETs to contact every network node in order to find and maintain routing tables [9], to discover a node [5] and for reputation management [13]. In large scale mobile networks the transmission range of a node can be much smaller than the size of the network. The solution to maintain connectivity is to use some nodes to retransmit (relay) messages in order to eventually reach all the nodes. However, if every node relays a given message, this will generate too much duplicates and will create problems related with battery depletion and bandwidth use.

It is often possible to benefit from redundancy in the topology so that all nodes are reached, even if only some do active transmissions. Therefore, several mechanisms have been proposed to optimize the number of relay nodes that participate in a given broadcast (e.g. [11, 7]), to name a few). A complementary optimization strategy is to stop an ongoing broadcast when one can determine that the broadcast task (e.g. find a given resource) has been fulfilled and there is no advantage in continuing the query dissemination.

For sake of motivation, consider applications for WUSNs (Wireless Underground Sensor Networks) where the nodes are connected via multi-hop links along several miles. This is a particularly challenging scenario, as the nodes are hard to access and maintain, and the topologies exhibit very long multi-hop routes [17]. Now consider the task of finding a given team of miners using the multi-hop infrastructure. Clearly, being node energy conservation a paramount concern, it would make sense to stop the query broadcast process once the team is found.

Many routing protocols implement partially optimal solutions that rely on variations of flooding mechanisms (e.g. [2]).

In this paper we compare the performance of stopping broadcast algorithms (BERS and BERS*) with controlled flooding based algorithms (ERS and ERS-TTL). This performance comparison explores the trade-offs among delay and energy expenditure, striving for efficient broadcast optimizations on networks with many nodes and a topology that favours long paths (and diameter). Stopping the broadcast queries has an impact in latency, which can be justified when exploring delay tolerant characteristics of large scale networks. Further developments of stopping broadcast techniques can be used to save the battery power of the mobile devices, enabling optimizations of broadcast algorithms for large scale MANETs.

2. RELATED WORK

Broadcasting protocols are widely used in MANETs for searching purposes and they were associated to message dissemination for all network nodes [6]. Floodind, the most simple implementation of broadcast, creates several problems in the MANET context [11], and more reasonable energy aware solutions, have been proposed to limit the broadcast scope. The range of a flooding area can be controlled by establishing a distance limit to the source or by defining a hop limit count [9, 15]. An example of an hop limit count is the successive geographical searches as performed by the **Expanding Ring Search (ERS)**. The ERS is used by reactive routing protocols such as DSR [9] or AODV [1] and by other discovery mechanisms [5, 4]. The ERS broadcasts a query by flooding, using the BFS (Breath-First Search) algorithm. Each broadcast is issued with a hop limit stored in a TTL (time-to-live) field, decremented by every node that retransmits it. A node receiving the message for the first time decrements the TTL and retransmits it if still non zero. If a previous attempt is unsuccessful, the query is reissued by the originator node, with a bigger hop limit, thus increasing the radius of the searching ring. Unfortunately, the accumulation of transmissions on the successive rings of ERS can have a great impact on energy and latency. The **TTL based ERS (ERS-TTL)** [8] is an hop-based flooding control [5] similar to the ERS. It uses the network dimension (D) to specify the hop limit search. The ERS-TTL uses a three-ring searching scheme where the TTL assumes the values $(1, \frac{D+1}{2}, D)$. An alternative study, using a dynamic programming formulation, revealed other sequences of TTL values that minimise the transmissions cost [4].

The **Blocking-ERS (BERS)** technique was created to improve the energy efficiency of the ERS process [12]. BERS broadcast the searching query with each node delaying the retransmission by twice the number of hops currently traveled hops, in the received message. When the resource is found a message is sent back to the source node. Then the source node broadcasts a *stop instruction* that contacts all nodes that issued the initial broadcast, thus terminating the discovery process. BERS avoids the successive discovery rings created by the initiator node in the ERS, because the relay nodes waits for an incremental double hop time count, before further disseminating the query. BERS can improve energy efficiency at the expense of latency. However, BERS is vulnerable to jitter in the propagation of the *stop instruction*, which may prevent the termination of the propagation.

The **enhanced BERS (BERS*)** approach improves the latency of the discovery process [15]. BERS* uses the same mechanism of BERS, but the waiting time is reduced to half at the relay nodes. Using this mechanism, the broadcast will continue for one more hop until the stop message has time to arrive to the discovery ring edge.

Searching mechanisms based on ERS [14] trade-off energy for latency. This is justified by the stringent power requirements of MANETs.

3. EVALUATION

In our simulation scenario all the created networks have the same dimension, keeping constant the number of nodes. The comparison study considers variations in the number of node resources, and measure resource ratios by considering the number of resources divided by the total number of nodes. The resources are randomly distributed, and a successful response is considered when the first resource is found.

The limited broadcast algorithms are evaluated considering two type of metrics: latency and retransmission ratio. **Latency** is the estimated time measured by the number of transmission slots until the initiator node receives a successful reply. An estimate of **retransmission ratio** is given by the number of transmissions until the query process ends divided by the number of network nodes. The energy consumption is estimated by the retransmission ratio. If a process receives an already relayed message, it will consider it as a duplication. The message is dropped and not relayed again. These metrics are presented in function of the **resource density**, that gives the percentage of nodes which have allocated resources that the query tries to find.

3.1 Comparing the algorithms

The algorithms described above have distinct termination conditions. The flooding algorithm stops by itself, when the transmitted message reaches the most distant node and there are no more unvisited nodes. Both ERS and ERS-TTL stop when the target resource is discovered and the TTL expires or eventually when the expanding ring floods the entire network. If a weak assumption of *at least one process has the resource target* is made, the termination condition of the expanding ring algorithm is simplified and occurs when the resource is eventually discovered, however the query continues for a number of rounds until it reaches the network frontier or TTL expires. Both BERS and BERS* stop when the target resource is discovered and the stopping message reaches all the nodes that were already part of the initial broadcast.

One of the main difference between the stopping broadcast algorithms and ERS based algorithms is that although both can lead to more than one broadcast, the stopping mechanisms avoid using multiple secondary broadcasts, to keep expanding the covered region. Stopping broadcast algorithms can tune the delay value to balance the need to have a small latency increase and to minimize the number of nodes that are involved in the broadcast until it is cancelled.

3.2 Simulation environment

To compare the performance of the distinct stopping algorithms, several network topologies were experimented. The communication model uses a simplified wireless radio communication model, were a radio message reaches all the

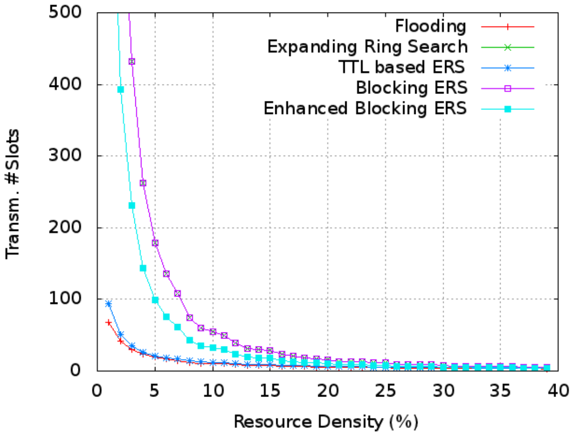

Figure 1: Latency of searching algorithms using Path topology

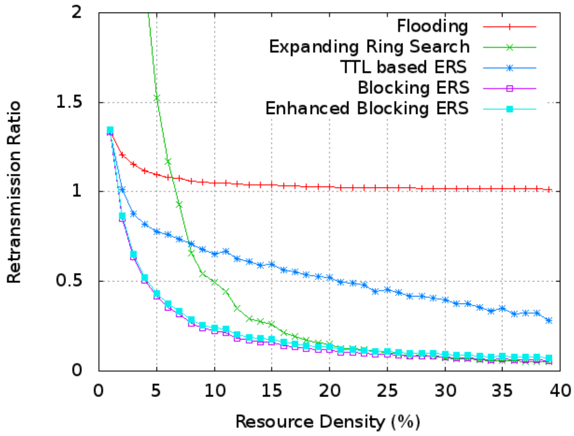

Figure 2: Communication overhead of searching algorithms using Path topology (energy estimation)

nodes in the neighbourhood radius. The simulator generates several network graphs to model the network topology. The topologies studied, are all derived by limiting node connectivity by an euclidean distance limit to radio range. The *Random Geometric* topology covers the general case of surface MANETs, the *Tree* topology represents a topology without multi-path routes, while the *Path* topology studies the performance on a single path of nodes. The simulation environment uses fixed time slot windows, without considering packet loss or radio interference. The radio connectivity is modelled by the network graph topology. Node graph neighbours are associated with radio stations nodes which are one hop distant and can be reached during the slot time window.

Given the small time frame where each broadcast is expected to occur, it is assumed that node movement is not sufficiently fast to introduce relevant changes in network topology during the transmission. Therefore, node movement is not included in the scenarios. However, since values are averaged among randomized networks, some of the dynamics that are typical of mobility are considered.

The simulation collects data for statistical analysis comparing ERS, ERS-TTL, BERS and BERS* searching mechanisms. Results are the average of 2000 simulation runs for each network topology class. Each run consists on the random deployment of 100 nodes respecting the topology class. All the algorithms were submitted to a more adverse simulation scenario (modelling MANETs), using a random geometric network graph. Target resource distribution is controlled by the resource density parameter that regulates the number of resource copies available. The resource nodes are distributed uniformly at random across the network. The initiator node i_0 is randomly selected among the available network nodes. The resource copies are generated with ratios between 1% and 40%. Resource density above 40% is not represented, because the probability of finding resources in the nearby nodes is sufficiently high and all the algorithms (except flooding) have equivalent performance.

3.3 Results

Figures 1, 3 and 5 show that the best latency is achieved by the flooding scheme for low resource density. The latency

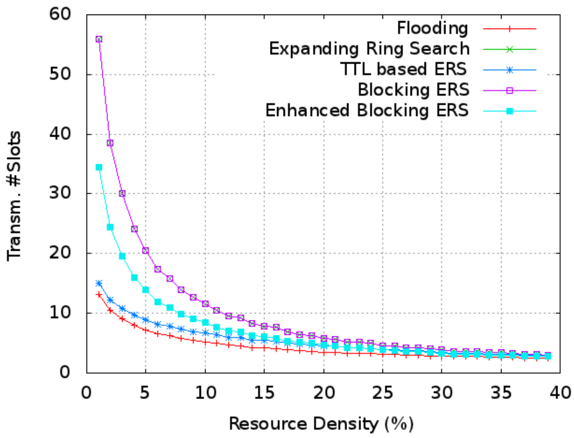

Figure 3: Latency of searching algorithms using Tree topology

penalization is the price penalty to pay (by all the tested algorithms) to obtain better energy performances.

Path Topology. Figure 1 shows that ERS, BERS and BERS* exhibit quadratic evolutions in the latency. This is specially relevant for low resource density, where search times can impact algorithm usefulness.

It should be noted that ERS and BERS exhibit similar latency and therefore the results are overlapped in Fig 1 and Fig 3. Figure 2 shows that, BERS* and BERS have similar energy performance, although as shown before, BERS* has better latency performance. The stopping broadcast scheme is clearly the best mechanism to explore if the energy is a critical resource on a path graph.

Tree Topology. The evolution of latency in the tree topology is similar to the path topology, with equivalent performance of BERS* and ERS-TTL. The better energy performance of the ERS is directly associated with the ring geographical node position and the tree topology. In tree topologies, the expanding ring schema is the most energy efficient of the compared algorithms.

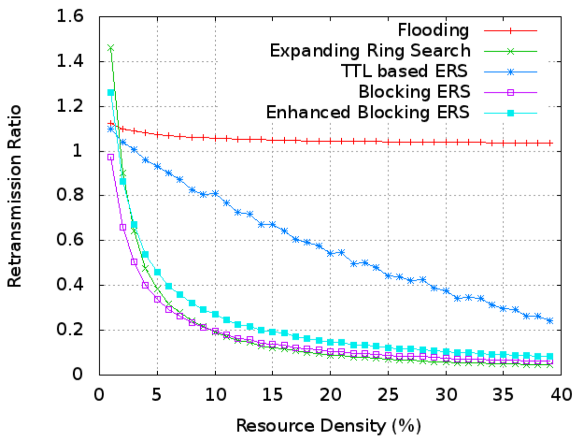

Figure 4: Communication overhead of searching algorithms using Tree topology (energy estimation)

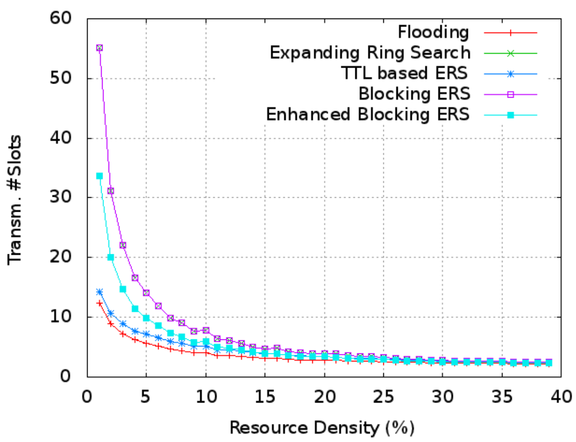

Figure 5: Latency of searching algorithms using Random Geometric topology

Random Geometric Topology. A coarse modeling of the topology of MANETs can be approached by random geometric graphs [16, 10]. In Figure 5 one observes that the cost in latency is significantly smaller for stopping broadcast algorithms, when compared with the ERS-TTL optimization. Figure 6 shows that they also have good energy performance.

Discussion on the results. Figures 2, 4 and 6 are estimations of the retransmission ratio of all algorithms. The broadcast stopping algorithms have a very significant reduction of the retransmission ratio, revealing good characteristics for the demanding WUSN settings. Results show that the stopping broadcast can improve the performance of ERS, when the available resource rate is between 1% and 15%. It was also observed that, when the copies are further than a (D+1)/2 hops distance from the initiator, the stopping mechanism has better performance than ERS, but this property is not always visible when the copies are randomly distributed. By choosing initiator location among a random location or a fixed one, we observed that either option does not change the performance in both algorithms.

Not surprisingly, it can be observed that if the number of resource copies increases, the probability that the resources appear nearby the initiator also increases, and the ERS is better than stopping mechanisms. ERS will find the resource in the first searching ring, without any stopping cost.

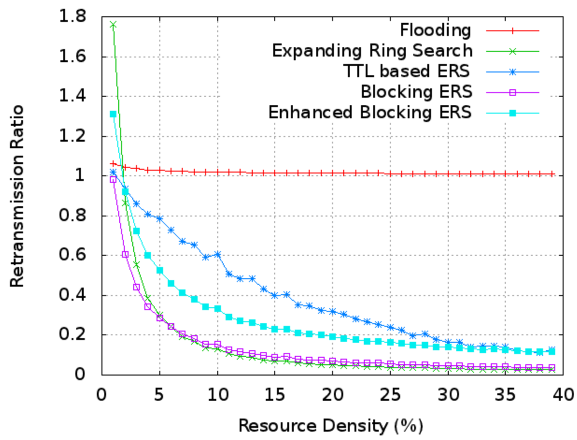

Figure 6: Communication overhead of searching algorithms using Random Geometric topology (energy estimation)

Impact of the delay time in the success of the chasing packets. We can define the delay time as a parametrized fraction of the number of travelled hops as $Delay = \frac{2 \times hop}{M}$ where $M = \{1, 2, 3, ...\}$ is an integer sequence. This model generalises the studied algorithms with stopping messages, making BERS and $BERS^{\star}$ particular instances, respectively for $M = 1$ and $M = 2$. For M values greather than 2 the delay will decrease and more additional hops are necessary to stop the query process, thus improving latency while degrading energy efficiency. Simulation results show that chasing packets can always stop the query within additional $M - 1$ hops after the Hop level at which discovery occurred.

4. FUTURE DIRECTIONS

In terms of evaluation the next obvious step is to confirm the insights on the generalised model in a simulation setting with variable transmission times and lower level interference of transmissions.

We will focus on the evolution of the stopping broadcast strategy, by considering the study of variable delays so that a constant fraction of the network is explored in each time unit by the slow broadcast. We also aim to explore modifications of the strategy that allows to initiate the stopping broadcast in the node where the resource is found, avoiding the communication step with the initial node. This will introduce additional complexity as the covered areas of the two broadcasts will differ more substantially.

5. CONCLUSIONS

The ERS (Expanding Ring Search) searching mechanism (used for example in DSR and AODV) is a sequence of floods that have an expanding scope limit, in order to avoid flooding the entire network when searching for a specific resource. For large-scale MANETs it will be important to have the possibility to stop the propagation of a query once the answer is found.

This research presents an initial evaluation showing that there are reasons to believe that stopping broadcast optimizations can improve flooding implementations, helping to extend the lifetime of battery based devices in multi-hop networks. Some solutions are already available for broadcast optimization, however there is still an opportunity to contribute with new solutions that can improve the performance of previous algorithms.

One of the main advantage of the stopping mechanism is the absence of multiple discovery attempts that are present in the ERS. Knowing the network size, a requirement for ERS, can be a very hard task with too much battery power wasted. Stopping broadcast solutions do not require previous topology information and thus are also more adequate for handling dynamics in the topology.

6. REFERENCES

[1] *AODV routing protocol implementation design*, Aug. 2004.

[2] H. AlAamri, M. Abolhasan, T. Wysocki, and J. Lipman. On optimising route discovery for multi-interface and power-aware nodes in heterogeneous manets. *Wireless and Mobile Communications, International Conference on*, 0:244–249, 2010.

[3] A. Boukerche, B. Turgut, N. Aydin, M. Z. Ahmad, L. Bölöni, and D. Turgut. Routing protocols in ad hoc networks: A survey. *Computer Networks*, 55(13):3032–3080, Sept. 2011.

[4] N. Chang and M. Liu. Revisiting the ttl-based controlled flooding search: optimality and randomization. In *MobiCom '04: Proceedings of the 10th annual international conference on Mobile computing and networking*, pages 85–99, New York, NY, USA, 2004. ACM.

[5] Z. Cheng and W. B. Heinzelman. Flooding strategy for target discovery in wireless networks. *Wirel. Netw.*, 11:607–618, September 2005.

[6] B. Garbinato, A. Holzer, and F. Vessaz. Context-aware broadcasting approaches in mobile ad hoc networks. *Comput. Netw.*, 54:1210–1228, May 2010.

[7] Z. J. Haas, J. Y. Halpern, and L. Li. Gossip-based ad hoc routing. *IEEE/ACM Trans. Netw.*, 14:479–491, June 2006.

[8] J. Hassan and S. Jha. Performance analysis of expanding ring search for multi-hop wireless networks. In *Vehicular Technology Conference, 2004. VTC2004-Fall. 2004 IEEE 60th*, volume 5, pages 3615 – 3619 Vol. 5, sept. 2004.

[9] D. B. Johnson, D. A. Maltz, and J. Broch. Dsr: The dynamic source routing protocol for multi-hop wireless ad hoc networks. In *In Ad Hoc Networking, edited by Charles E. Perkins, Chapter 5*, pages 139–172. Addison-Wesley, 2001.

[10] H. Kenniche and V. Ravelomananana. Random geometric graphs as model of wireless sensor networks. In *Computer and Automation Engineering (ICCAE), 2010 The 2nd International Conference on*, volume 4, pages 103 –107, feb. 2010.

[11] S.-Y. Ni, Y.-C. Tseng, Y.-S. Chen, and J.-P. Sheu. The broadcast storm problem in a mobile ad hoc network. In *Proceedings of the 5th annual ACM/IEEE international conference on Mobile computing and networking*, MobiCom '99, pages 151–162, New York, NY, USA, 1999. ACM.

[12] I. Park, J. Kim, and I. Pu. Blocking expanding ring search algorithm for efficient energy consumption in mobile ad hoc networks. In *WONS 2006 : Third Annual Conference on Wireless On-demand Network Systems and Services*, pages 191–195, Les Ménuires (France), Jan. 2006. INRIA, INSA Lyon, IFIP, Alcatel. http://citi.insa-lyon.fr/wons2006/index.html.

[13] F. Perich, J. Undercoffer, L. Kagal, A. Joshi, T. Finin, and Y. Yesha. In reputation we believe: query processing in mobile ad-hoc networks. In *Mobile and Ubiquitous Systems: Networking and Services, 2004. MOBIQUITOUS 2004. The First Annual International Conference on*, pages 326 – 334, aug. 2004.

[14] I. Pu, J. Kim, and Y. Shen. Energy-time efficiency of two routing strategies with chase packets in expanding ring search. In *Telecommunications (ICT), 2010 IEEE 17th International Conference on*, pages 742 –747, april 2010.

[15] I. Pu and Y. Shen. Enhanced blocking expanding ring search in mobile ad hoc networks. In *New Technologies, Mobility and Security (NTMS), 2009 3rd International Conference on*, pages 1 –5, dec. 2009.

[16] Y. Shang. Exponential random geometric graph process models for mobile wireless networks. In *Cyber-Enabled Distributed Computing and Knowledge Discovery, 2009. CyberC '09. International Conference on*, pages 56 –61, oct. 2009.

[17] C. Wenqi and X. Zhao. Multi-hop routing for wireless network in underground mines. In *Wearable Computing Systems (APWCS), 2010 Asia-Pacific Conference on*, pages 337 –340, april 2010.