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Integrated Wireless Communication Protocol for Ad-Hoc Mobile Networks

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Abstract

Wireless ad-hoc networks have recently emerged as a relevant research topic. The management of ad hoc networks raises many interesting problems, and adding the mobility to the network's components increases the number of these challenges. The approaches to the real-time communication among the network's units should guarantee robustness, flexibility and scalability, while meeting the timing constraints on real-time messages.

Our goal is to build an integrated communication framework suitable for ad-hoc networks of mobile units. The main features to achieve are: robustness, scalability, and dynamic configurability. In this paper we outline the main challenges to be solved and we propose our solutions. They are based on a set of integrated protocols focused on the management of the communication and the self-organization of the network. The main topics covered in the work are: the MAC protocol with real-time features, the cellular approach, the resource reservation, the management of the network topology and power-aware issues.

1 Introduction

The world is changing faster and faster. The research, the new approaches and the discoveries in many technological fields, such as information technology, electronics, medical applications etc., are carrying on these changes. The progress of wireless communication technology allows the development of distributed applications based on interconnected units. The price of the components is gradually decreasing, thus ambitious applications can be realized at a relatively low cost. Typical applications of wireless connected networks are for monitoring and exploration purposes. Many situations require the acquisition of huge amount of data from the environment to improve the knowledge about a specific problem, thus demanding the use of efficient approaches and solutions. In most applications, the communication between distant units is based on a wired backbone. However, in the situations considered above, a wired infrastructure cannot be used, hence a full autonomy of the network can only be achieved through an ad-hoc network. Moreover, since the nodes interact with the environment, most of the activities carried out by the network will be characterized by timing constraints that need to be enforced on the tasks to guarantee a minimum level of performance.

In this paper we briefly discuss a set of integrated protocols focused on the management of the communication and the self-organization of ad-hoc networks made by mobile units [5]. In particular, we address the following topics:

1. real-time contention-free medium access control (MAC) protocol;
2. cellular approach to take advantage of the multiple frequency transmissions;
3. management of the network topology;
4. robust time-constrained resource reservation protocol;
5. power-aware related issues.

The main features we want to achieve are: robustness, scalability and dynamic configurability. In addition, one of the main goals of the project is to achieve the required performance with no external assistance (like GPS or other external global information), so that our approach will be suitable for critical environments that account for the impossibility, or just the absence, of external support. In our approach, the management of the whole network is built on the basis of system data exchanged among the nodes only.

Figure 1 illustrates the relationships between our goals and the solutions that are under development to solve them.

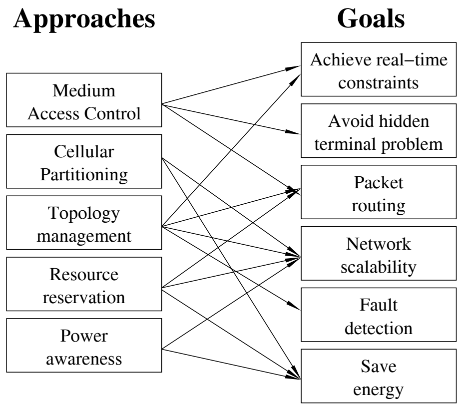

Figure 1: Table resuming the relations between goals and approaches.

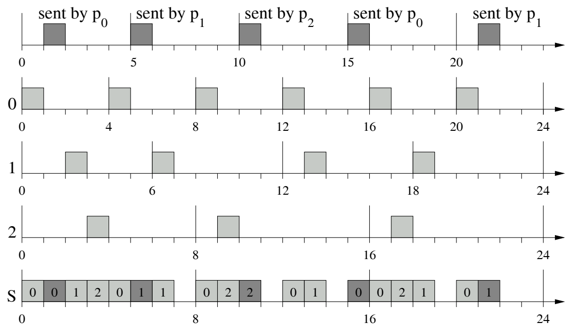

Figure 2: Example of reserved periodic message stream used in a round-robin fashion by the network's nodes.

2 Real-time MAC protocol

The real-time constraints in the communication among the nodes of the network can only be fulfilled with appropriated MAC level support. MAC protocols that achieve high bandwidth utilization (like in the TDMA) as well as a predictable real-time communication are already available. Our option is to adapt the *Implicit EDF* (I-EDF) MAC protocol, originally proposed in [1] for networks of steady sensors, to cope with node mobility and dynamic network's re-configuration The I-EDF MAC protocol is based on the EDF scheduling algorithm [6] to guarantee the real-time requirements of the communication. It uses a time-triggered communication in which the scheduler is local to each node, and the communication requirements of the whole network are known by each node. Keeping the clocks synchronized, each node exactly knows when it can broadcast without risks of collisions, implicitly eliminating the channel contention and also the hidden node problem [10]. The main disadvantage is that it requires a tight clock synchronization among all the nodes in a cell to avoid that clock drifts cause overlapping in the transmission. A method for dealing with clock drifts is to insert extra time windows (of size equal to the maximum clock difference) between slots, so that messages transmitted before or after the beginning of a slot will not cause collisions. As a consequence, time synchronization must be implemented efficiently, to reduce the overhead introduced in the messages, and with high precision, to reduce the size of the extra windows between slots. The original version of the protocol does not explicitly manage dynamic changes in the network, which is one of our main goals.

Our approach is to reserve a periodic message stream, regularly scheduled as a normal node broadcasting, to propagate global information in the network. In each period, the transmission slots are used by a different node in a round-robin fashion (see Figure 2). The reserved stream is used for achieving clock synchronization among the nodes, spreading the topological view of the network, propagating resource reservation requests and allowing external nodes to synchronize with the network's schedule in order to join the network.

3 Cellular approach

Although it is known that broadcasting global information about the network put severe scalability limits [9], a partition-based approach can be effectively used to allow the network growing. The cellular approach is widely used to allow scalability in many communication protocols [1, 4, 7].

Clustering nodes into partitions is an operation that allows achieving several goals. For instance, it allows to improve scalability, reduce the number of hops needed to route a message, increase the coverage of the network, and allow data-centric addressing in the whole network [9] (i.e., an information can be asked to a partition instead of a single node).

In our approach, the global information introduced in Section 2 is broadcasted at a partition level only, so that it does not introduce too much overhead in network management and it does not affect the global performance of the network. The network partitioning can be location-based or service-based (routing or power awareness). Special nodes (gateways) handle the inter-cluster communication. The selection of the the gateway can be done on the basis of the current topology and the proximity with adjacent clusters (in contrast with LEACH [4], that selects the so called cluster head randomly). Moreover, the network can dynamically rearrange the network partitioning to comply with QoS requirements using the resource reservation mechanism explained in Section 4.

4 Resource reservation

Resource reservation issues are the basis for achieving online network configuration capabilities. They include:

- the chance of dynamically varying the bandwidth requirements of the nodes;
- the ability to add or remove nodes from the network, affecting the network topology;
- the possibility to change the transmission frequency due to high noise or interferences.

To comply with the real-time requirements of the communication, the reservation process must be predictable and robust. In [2], we introduced some basic ideas on how to build the process on top of a contention-free real-time MAC protocol. Dynamic resource reservation implies dynamic communication requirements. In a time-triggered protocol with distributed scheduling it is essential that all changes in resource allocation (e.g., bandwidth) are agreed by all nodes, at the same time.

The resource reservation process must take into account the round-robin organization of the system information broadcasting. We are working on an agreement strategy based on positive aggregated acknowledge that allows a node to establish that an agreement has been reached by inspecting a data structure that is updated and re-transmitted by all the nodes in the network.

5 Network topology management

In a scenario in which the nodes are not connected with each other, it is important to provide an overall view of the current network topology. This is useful for:

- planning the movements of the units;

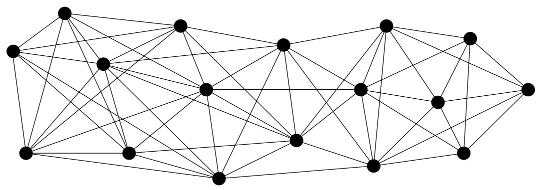

Figure 3: A network of highly connected nodes.

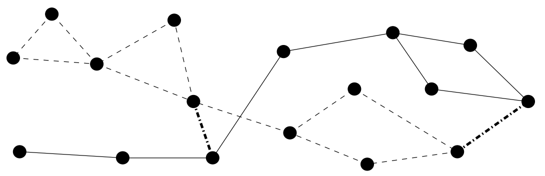

Figure 4: Network divided in two clusters of poorly connected nodes.

- building a coherent working strategy;
- monitoring the activity status of each single network's member;
- supporting routing by finding a path between any two connected nodes;
- supporting the detection of absent nodes, e.g., nodes that crashed.

While in [5] the routing problem is related to the node mobility, in [3] and [8] the importance of topology management it is clearly discussed as a mean for reacting to events with specific control actions.

For our purpose, the network topology must be kept updated considering the round-robin organization of the system information broadcasting. We are working on an algorithm that gives an overall view of the links among the nodes in the network. Such an algorithm is based on an update-and-broadcasting method that allows the knowledge about the network topology and the reliability of the links to be spread among all the members of the network. The connections between node mobility and the validity of the information over time must be drawn.

6 Power-aware issues

Saving energy is a very important goal in most embedded systems. In wireless networks, one of the most energy-consuming component is the transceiver. To reduce the energy consumption of the transceiver, two approaches can be adopted:

1. the communication hardware can be switched off when not used;
2. the transmission power can be reduced.

Both solutions should keep the network connected and should consider the possibility of grouping the nodes into different clusters. Hence, it is clear that power-aware issues are tightly related with scalability, and can be dealt with an approach based on the topology knowledge.

Our approach aims at obtaining a suitable combination of the two methods in order to improve the energy saving, while achieving a minimum level of connectivity in the network, guaranteeing the desired quality of service. Moreover, since different units can have different power constraints, a global setup for the optimal power exploitation can be achieved using our distributed agreement processes.

Figure 3 and 4 illustrate the same network with different levels of connectivity and different clustering topologies. It is clear that the solution shown in Figure 3 favors a more efficient routing, whereas the one in Figure 4 privileges energy saving.

7 Conclusions

In this paper we addressed the main issues related to the development of a wireless ad-hoc network of mobile units. We have identified several inter-dependent components dedicated to different objectives: the MAC protocol with real-time features, the cellular approach, the resource reservation, the management of the network topology and power awareness. These topics were discussed in order to relate them with our main goals: robustness, scalability, and dynamic configurability.

In this work, we also drawn the guideline of the solutions. These approaches are currently under development and under evaluation in order to integrate them into a robust, flexible, and scalable protocol that supports adaptation in wireless networks of mobile units. The development is being carried out in two complementary ways: finding theoretical results for proving some properties of the approaches and implementing a visual discrete-time simulator to test new solutions. Moreover, a real implementation of the framework is under planning.

References

[1] M. Caccamo, L. Y. Zhang, L. Sha, and G. Buttazzo, "An Implicit Prioritized Access Protocol for Wireless Sensor Networks", *Proceedings of the IEEE Real-Time Systems Symposium*, December 2002.

[2] T. Facchinetti, G. Buttazzo, M. Caccamo, and L. Almeida, "Wireless Real-Time Communication Protocol for Cooperating Mobile Units", *Proceedings of the 2nd International Workshop on Real-Time LANs in the Internet Age (RTLIA 2003),* Porto, Portugal, July 1, 2003.

[3] M. Gerharz, C. de Waal, M. Frank, and P. Martini, "Link Stability in Mobile Ad Hoc Wireless Networks", in *Proc. of the 27th IEEE Conf. on Local Computer Networks,* November 2002.

[4] W. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "Energy-efficient communication protocols for wireless microsensor networks", *in Proc. Hawaiian Int. Conf. Systems Science,* January, 2000.

[5] B. Hughes, and V. Cahill, "Achieving Real-Time Guarantees in Mobile Ad Hoc Wireless Networks", in *Proc. of the Work-in-Progress session of the 24th IEEE Real-Time Systems Symposium,* pp. 37-40, December 2003.

[6] C. L. Liu, and J. W. Layland, "Scheduling Algorithms for Multiprogramming in a Hard Real-Time Environment", *Journal of the ACM* 20(1), pp. 40–61, January 1973.

[7] A. B. McDonald, and T. Znati, "A Mobility Based Framework for Adaptive Clustering in Wireless Ad-Hoc Networks", *IEEE Journal in Selected Areas in Communications (JSAC),* 17 (8). pp. 1466-1487, August 1999.

[8] T. Srinidhi, G. Sridhar, and V. Sridhar, "Topology Management in Ad Hoc Mobile Wireless Networks", in *Proc. of the Work-in-Progress session of the 24th IEEE Real-Time Systems Symposium,* pp. 29-32, December 2003.

[9] J. Stankovic, T. Abdelzaher, C. Lu, L. Sha and J. Hou, "Real-Time Communication and Coordination in Embedded Sensor Networks", *Proceedings of the IEEE*, vol. 91, no. 7, pp. 1002-1022, July 2003.

[10] F. Tobagi, and L. Kleinrock, "Packet Scheduling in Radio Channels: Part II-The Hidden Terminal Problem in Carrier Sense Multiple Access and the Busy-Tone Solution", *IEEE Transactions on Communications,* 23 (12). pp. 1477-1433, December, 1975.