A Decentralized Protocol for Wireless Communication in Mobile Sensor Networks

PAOLO DI GIAMBERARDINO, IVANO BERGAMASCHI, ANDREA USAI
Department of Computer and System Sciences “Antonio Ruberti”
University of Rome “La Sapienza”
Via Ariosto 25, 00185 Rome
ITALY
paolo.digiamberardino@uniroma1.it, sir.ivan.henger@hotmail.it, andrea.usai@dis.uniroma1.it

Abstract: The paper presents a light-weight dynamic protocol for data transmission between nodes in mobile sensor networks. Under the assumption that the network is connected, a multi hop data transfer is performed. It is dynamically reconfigurable once the number of the nodes varies and it is light-weight thanks to the local routing management, without routing table, using limited computing power. A innovative data structure called “the Postman Bag” is introduced to spread data collected by sensor quickly and simply. Some considerations about performances are reported, on the basis of some simulations and tests.

Key–Words: Mobile sensor network, Data transmission, Protocol, Wireless communications, Local management, Dynamic reconfiguration.

1 Introduction

Distributed sensors systems and networks are gaining a relevant position in larger and larger fields of research and applications. For example, sensor networks can be involved in monitoring or surveillance tasks for large areas or in hazardous structures as well as in presence detection and distribution of people in particular areas or buildings during critical events, and so on.

Taking into account the limited range of measurement for a sensor, the problem of maximizing, for a given set of sensors, the number of detectable events or in general the field of measure of the sensor network is known in literature as the area coverage problem (for example [1, 2]). Using fixed positions for the sensors, the coverage problem can be faced in terms of collocation of sensors in the area under measurement. Thanks to the different aspects involved, there is a large literature on the theme (for example [3, 4, 5, 2] and references therein).

More recently, the idea of using mobile sensors has been proposed where the mobility is used for the first sensors allocation and for occasional reconfiguration tasks (for example [6, 7, 8]).

Increasing the motion capabilities, the so called dynamic sensors networks or mobile sensors networks have been proposed, with sensors that take measures while moving continuously. This approach increases the flexibility of the sensor network and reduces the number of sensors but, on the other hand, pointwise continuous measurement is no longer possible: only a maximum time interval $T_{\text{MAX}}$ between two consecutive measures at the same coordinates can be guaranteed.

The coverage area problem in this case is not posed in terms of collocation of sensors but as suitable trajectories for the moving sensors in presence of some constraints. Some results are in [9, 10, 11, 12, 13, 14]. The problem of communications between nodes in a mobile sensor network involves different data having to be transmitted all over the network. In fact, together with the measurement data that each sensor acquires, also informations about the status of the nodes, at least in terms of position, neighborhood radio and sensing connections, energy status, operative conditions and so on, must be notified to all the nodes in the net. Like in other local ad-hoc networks as in military field operation,
disaster control, etc., one of the most sensible topics is the medium access control (MAC) protocols, which coordinate the efficient use of the limited shared wireless resources. However, in these wireless networks, the limited wireless spectrum, low sophistication, and the high mobility together impose significant challenges for MAC protocol design to provide reliable wireless communications with high data rates. MAC protocols are an active research area for more than 30 years now, and there exists a huge body of literature (some recent examples are [18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29]).

One of the most used is the fixed assignment protocols: the available resources are divided between the nodes such that the resource assignment is long term and each node can use its resources exclusively without the risk of collisions.

Typical protocols of this class are TDMA, FDMA, CDMA, and SDMA.

The Time Division Multiple Access (TDMA) scheme subdivides the time axis into fixed-length superframes and each superframe is again subdivided into a fixed number of time slots. These time slots are assigned to nodes exclusively and hence the node can transmit in this time slot periodically in every superframe. TDMA requires tight time synchronization between nodes in order to avoid overlapping of signals in adjacent time slots.

In Frequency Division Multiple Access (FDMA), the available frequency band is subdivided into a number of subchannels that are assigned to nodes which can transmit exclusively on their own channels. This scheme requires frequency synchronization, a relatively narrow band filters, and the ability of a receiver to tune the channel used by a transmitter. Consequently, an FDMA transceiver tends to be more complex than a TDMA transceiver.

In Code Division Multiple Access (CDMA) schemes, the nodes spread their signals over a much larger bandwidth than needed, using different codes to separate their transmissions. The receiver has to know the code used by the transmitter; all parallel transmissions using other codes appear as noise.

Finally, in Space Division Multiple Access (SDMA), the spatial separation of nodes is used to separate their transmissions. SDMA requires arrays of antennas and sophisticated signal processing techniques and cannot be considered a candidate technology for WSN.

A new class of protocols developed for WSN has appeared: examples are Direct Diffusion, Low-Energy Cluster Hierarchy (LEACH) and Sensor Protocols for Information via Negotiation (SPIN).

The Direct Diffusion protocol is data-centric and highly adaptive as it selects empirically low delay paths based on local interactions. This also implies that the non end-to-end approach is adopted and that there is no need for global IDs throughout the net.

LEACH organizes the network into clusters. Each node can decide whether to become a cluster head according to a certain probability specified a priori. LEACH differs from the other protocols cited here since it adopts direct instead of multi-hop transmission.

The last protocol, SPIN, is designed to address three deficiencies of flooding: implosion, overlap and resource blindness. Implosion refers to the waste of resources arising when a node forwards a message to a neighbour although the latter may have already received it from another source. Overlap occurs when two nodes sense the same region and produce and push into the network the same results. Resource blindness denotes the incapability of the protocol to adapt the nodes behavior according to its power status.

In this paper, a novel Dynamic Light-Weight protocol is proposed, able to efficiently manage the MAC side problem and at the same time the routing problem in a mobile sensor network. The proposed protocol works like a postman who has to collect mail and, at the same time, deliver it to a certain number of locations without passing through a central post office. The protocol makes use of a unique data structure that, on the analogy of what just said, will be denoted Postman Bag. The Bag is used to spread sensors informations in a fast and simply way, without the necessity of using any routing table or hierarchical structure into the net, using a policy similar to a token passing scheme.

In Section 2 the protocol is described and all the phases (initialization, transmission, updating, reading and so on) are presented and discussed in its Subsections. Some critical cases are presented and solutions are illustrated. Section 3 is devoted to present some considerations about the performances related to the protocol and the transmission complexity on the basis of theoretical estimation, numerical simulations and a first implementation. Some conclusions are reported in Section 4, ending the paper.

## 2 Protocol Description

The proposed protocol is a light-weight dynamic protocol based on a unique data structure: the Postman Bag. The Bag is organized to store, sort and forward the information collected by the sensors network, in a simple, fast way. Among all nodes in the network, only the node holding the Bag is responsible for sending it to the successor. When a node receives the Bag,
it checks the presence of messages addressed to itself and can insert a message for another one. A successors list is also created analyzing the counter fields on the Bag following a special policy and after a handshake phase the real successor is detected.

In the present form, the proposed protocol works effectively and properly if some assumptions are verified. The first one is quite general and does not restrict the field of applications: the network must be represented by a connected graph. It is clear that, if this hypothesis is not fulfilled, there exist couples of nodes that cannot communicate each other directly nor using a multiple hop path through nodes. A second hypothesis, strongly related to the present version of the implemented protocol, is on the knowledge of the number of nodes in the network. This is necessary since the record transmitted must contain as many counters as agents of the network and a field that contains such a number.

The protocol is called dynamic because it is possible to change on the run the Bag structure, according to the increasing or the decreasing of the node population. It is also light-weight because the routing is managed locally, without routing table, and using a limited computing power. A half-duplex transmission antennas is used to overcome the hidden terminal problem and the exposed terminal problem.

Each node that receives the Bag performs three ordered distinct phases: 1) Bag Analysis, 2) Handshake, 3) Bag update and forward. An initialization phase is performed at the beginning of the process.

2.1 The protocol at work
The node which holds the Bag creates a list using specified Bag fields. Figure 1 shows the Bag format. In Figure 1-A, Start and End identify the begin and the end of the Bag, Sor and Des the source and destination nodes ID, Check the checksum for the Bag. The total number N of the nodes in the network is stored in P Num. This number is increased/decreased each time an element joins in or parts from the network. A different transmission frequency is used for changing this field dynamically. The N node counters Ai, one for each node of the network and ordered in a ring-like way, are modified every forward step of the Bag (Figure 1-A1). The values in these fields and the order in the Bag are the keys to create the list for the Hand-Shake phase. The message number M Num is the total number of messages present in the Bag. Any time a node wishes to transmit a data from sensors or a status information or anything else, a message is generated and when the Bag reaches it, the message is stored in. All the messages have the same structure (Figure 1-A2). M Sor and M Dest identify the source and the destination node ID of the message, D1 and D2 are the data fields and TTL (time to live) represent the number of times the message has been forwarded. Every node holding the Bag contacts one of his neighbor through a hand-shake message. To reduce the transmission overhead, the hand-shake frame should be as small as possible, ensuring sender/receiver side a simple two way hand-shake. As illustrated in Figure 1-B, the fields in hand-shakes frames manage this operation.

When the Bag is created all the counters are set to zero.

2.1.1 Hand-Shake List Creation
When a node initializes or receives the Bag, it creates a list to perform the hand-shake phase. Each agent follows a check sequence to generate it. First of all the Bag sender is excluded and then the remaining agents are sorted in ascending counter order. If multiple nodes have the same counter value, a priority is associated according to the counters order. The node holding the Bag is always the last on the list. Figure 2 shows an empty bag at node B. B creates the list following the criteria explained above: C-D-E-B. In the present example the priority order is the alphabetical order related to the letters associated to the nodes.

2.1.2 Hand-Shake Phase
After the list creation, the Bag holder tries to reach the node in first position using a hand-shake message. If he cannot receive a reply message in a reasonable
Prefixed time, it will try to contact the next in the list. According to Figure 2, using the list C-D-E-B defined in the previous phase, the hand-shake with C fails, because C is not in B connection area, i.e. it is out of communication range. B discards C and tries with D. D accepts the hand-shake message and sends a response to B. B updates the Bag and then forwards it to D.

2.1.3 Updating the Bag

When a successor becomes available in the hand-shake phase, the Bag holder updates the Bag fields. First of all Sor and Des fields are updated and then the sender counter is increased by one. Before sending the Bag, the node checks its cache searching for messages. The node will continue adding messages in the Bag and increasing the M count of one unit for each message. When all the messages have been added, the Bag is forwarded. After the arrival of the Bag, the node performs a control for the messages present in the Bag, searching for its ID in each of the M Dest field. If a message directed to the Bag holder is found, the information inside are acquired, the message is deleted and the M count field is decreased by one.

Figure 3 shows these controls excluding the hand-shake phase already discussed. First of all C adds a message for A in the Bag, increasing its size. Then the Bag is passed to E, then B and, finally, A. Each of such nodes checks for messages addressed to it and then performs a control of M Dest field in order to pass over the Bag. In this scenario, only A acquires the message and decreases the size of the Bag.

2.2 Solution for Sink Nodes

Using the method illustrated above to generate the hand-shake list, if the network contains a sink node the Bag stops on it. This problem is avoided adding also the Bag-holder in the hand-shake list as the last node. As illustrated in Figure 4, the node B receives the Bag from A, and then creates the list, excluding, by construction, the Bag sender from it. B is a sink node and can reach A only. The used policy excludes the forwarding to A since it is the sender, so the Bag stops.
Figure 4: Sink node solution

is blocked on B. Adding B on the hand-shake list, the Bag is forwarded on the same node. The forwarding is performed only changing the B counter of one unit. A new list is created, excluding B, as sender, but now including A and the Bag is sent out of the sink.

2.3 Solution for Bag Looping

Another problem generated by the list creation policy is the Bag looping problem. The list is created following the node counters values, giving higher priority to nodes with lower counter number. If two or more agents join the network after a while, they can create a cycle in the network since each of them attracts the Bag due to its very low counter value. Then, the Bag will be forwarded between the nodes belonging to the loop until all their counters are increased enough to reach the counter values of the other nodes. This fact is illustrated in the left side of Figure 5. The solution adopted is based on the control of the gap between the max value of counter fields and the counter fields of the newcomer nodes. It has been chosen that if the gap is greater than two, the counter fields are updated to a value equal to the maximum value minus one. Right hand side of Figure 5 shows the steps and the effects of the corrective action. Operating in this way the proposed protocol managed simply topological structures like stars or crosses.

2.4 Network changing on the run

The proposed protocol allows nodes to join in or to part from the network dynamically. Before one or more elements enter or leave the graph, all the nodes have to be informed, using a different transmitting device or protocol or technique. Once the information reaches the node holding the Bag, it modifies the P num field and the Bag structure adding or deleting counter fields.

3 Performance Evaluation

In this Section, some considerations about the advantages and an evaluation of the performances for the proposed protocol are reported.

First of all, the proposed approach does not make use of any type of routing table. Only the local information collected analyzing the Bag are used for forwarding the data. This means that this solution can be adopted also in case of decentralized (local) control of the nodes motion.

From a computational point of view, the complexity for the protocol is evaluated in $O(n^2)$. In fact, for the analysis, the worst scenario in Bag forwarding phase is represented by $n^2$ jumps to deliver the Bag to every node at least one time. The Hand-Shake phase also has the same complexity order, i.e. $n^2 − 1$ attempts are required to reach a neighbour on the list.

In the proposed protocol, the time $T_{H−S}$ devoted to the hand-shake phase is always the same, thanks to the constant length of the messages in this phase. On the contrary, the Bag has variable length, depending on the number of messages contained, and its transmission time $T_{Bag}$ is greater than $T_{H−S}$. Then, a time evaluation, represented by $T_{max} = n^2 \cdot T_{Bag} + (n^2 − 1) \cdot T_{H−S}$. 


\( T_{H-S} \) can be approximated as \( T_{\text{max}} \simeq n^2 \ast T_{\text{bag}} \).

For the experiments, two different ways to managed the Bag and its length are considered. In the first scenario the Bag can store only one message and a node can use the Bag only after the message of predecessor is delivered. In the other situation the Bag stores a single message for each node of the net. A 16 Kbit/sec radio data rate is assumed and a node population between 0 and 30 is considered. Moreover, the case of a well-known topology structure like chain is considered for both the scenarios. Figure 6 plots the diffusion time vs. the number of nodes for the four cases. It is evident that structured topologies strongly reduce the time required to transmit over the network.

4 Conclusion

In the paper a routing protocol for data and command transmission between nodes in a mobile sensor network has been presented. It allows to send a message from any node to any other one. It does not require a priori time or bandwidth division for communication. It is robust with respect to dynamic change in the node number; moreover, the protocol does not require any knowledge of the motion strategy and of the node position: the only obvious assumption of full connectivity, i.e. the existence of at least one path between any couple of nodes at any time, is required. Local management with a low computational requirements makes it very interesting for distributed control approaches. Some simulations show the effectiveness of the proposed strategy. A first implementation on small network confirms such results. Implementations on large networks are coming soon.

References:


