

An Efficient Permutation Routing Protocol in Multi-Hop Wireless Sensor Networks

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Abstract

A wireless sensors network (WSN for short) can be represented as a graph, tree, or other structures. The structure is more or less important depending on the problem that we will deal with and the respect of constraints on WSNs. WSN (p, n) is a wireless sensor network of p stations with n items saved on it. In this paper we are interested in the permutation routing problem on multi-hop WSN(p, n). We derive a new protocol that performs with less number of broadcast rounds compared to the one in [3]. We present some simulation results comparing our protocols to the one in [3].

Keywords: Permutation Routing Problem, Wireless Sensor Networks, Hierarchical Clustering, Clique

1. Introduction

A sensor network is composed of a large number of sensor nodes which are densely deployed in an area. WSN can be deployed to provide continuous surveillance over an area of interest referred to as a sensor field [15]. Wireless sensor nodes perform collaborative work [15] via wireless communication channels to retrieve information about targets that appear in the sensor field or to exchange some information. Higher-level decision making can then be carried out based on the information received from the sensor nodes. These networks can be deployed in inhospitable terrain or in hostile environments to provide continuous monitoring and information [15], or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants [1, 6, 16]. Note that in sensor network energy is limited and we must minimize as possible the number of the broadcasts in order to increase the lifetime of the system.

There are two types of wireless networks: Single hop wireless networks in which each station can transmit or communicate directly with any other station. All the stations use the same channel to communicate, and the message broadcast by one of the stations on the common channel is simultaneously heard by all other stations. In the multi-hop wireless networks intermediate nodes are used to route message from the source to the destination.

The *Permutation Routing Problem*: Consider a WSN (n, p) of p sensors with n items saved on it. Each item has a unique destination which is one of the p sensors. Each sensor node has a local memory of size $\frac{n}{p}$ in which $\frac{n}{p}$ items are stored. It is important to note that in general, some of the $\frac{n}{p}$ items stored in the sensor, say i , have not i as destination sensor. And even, it can happen that none of these $\frac{n}{p}$ items belongs to it. In the other hand, the situation in which initially all items in i belong to i can also occur. The permutation routing problem is to route the items in such a way that for all $i, 1 \leq i \leq p$, sensor i recovers all its own items.

A large variety of permutation routing protocols in a single-hop Network are known today. However, these varieties of methods are not adapted in the case of multi-hop networks. One way to solve this problem is to partition nodes into clusters where principal node in each cluster, called cluster head, is responsible for routing items.

1.1. State of the art

The number of studies specifically targeted to permutation routing in single hop wireless networks has grown significantly. It is shown in [13] that the permutation routing of n items saved on wireless sensor network of p stations and k channels with $k < p$, can be carried out efficiently if $\frac{n}{p}k < \sqrt{\frac{p}{2}}$. In [12]. Datta in [4] derived a fault tolerant permutation routing protocol of n items saved on mobile Ad-hoc network of p stations and k channels (MANET(n, p, k) for short). He also assumed that in the presence of faulty stations some data items are lost. We came out with our work in [8] presenting a fault tolerant protocol which avoids the loss of items, and a randomized approach solving this problem was presented in [9]. The first energy-efficient permutation routing appeared in [14]. A more efficient energy-efficient permutation routing protocol was presented in [4, 5, 14]. In [19] Walls et al. propose an optimal permutation routing on mesh networks. Another approach as an application of an initialization algorithm appeared in [7]. All these approaches assume that the WSN is a single hop networks. At present there is one protocol that runs the permutation routing in multi-hop wireless networks [3], using $(k+1)n + O\left(\left|HUB_{\max}\right|\right) + k^2 + k$ broadcast rounds in the worse case. Where n is the number of the data items stored in the network, p is the number of sensors, $|HUB_{\max}|$ is the number of sensors in the clique of maximum size and here k is the number of cliques after the first clustering.

1.2. Our contribution

As in [3], we first propose to partition the network into single-hop clusters also named *cliques*. Secondly, we run a local permutation routing to broadcast items to their local destinations in each clique. Next we partition the cluster-heads of cliques with the hierarchical clustering technique [2]. We show how the outgoing items can be routed to their final destination cliques. We derive a Breath First Search tree (BFS tree) that we to perform the broadcastings of outgoing data items, contrary as in [3], where a general graph is used to broadcast these items. Therefore we can perform the process simultaneously on nodes. The goal of using the tree in our protocol is to perform some parallelism in the process. We give the estimations of the upper bound of the number of broadcast rounds in the worst case. More precisely we show that *the permutation routing problem* can be solved in $3n + 6 \log_2 k$ in the worst case, where k the number of cliques after the clustering in cliques. We present the experimental results comparison in terms of number of broadcast rounds between our protocols and the one in [3].

The rest of this paper is organized as follow: section 2 defines some preliminaries. In section 3 we present the efficient protocol for the permutation routing in multi hop wireless sensors network using a single channel. Section 4 deals with some experimental results. And a conclusion ends the paper.

2. Preliminaries

We assume that each station has a local clock which keeps synchronous time by interfacing with a Global Positioning System (GPS). Time is divided into slots.

As in [3], we assume that the n items denoted a_1, a_2, \dots, a_n are saved on a WSN(n, p) such that for every $i, 1 \leq i \leq p$, station i stores the items. Each item has a unique destination station. It is important to note that hereafter a sensor knows the destination of items it holds. In fact the data item it holds is a couple $S(s, d)$, where s is the real data item belonging to sensor source and d is the sensor destination. For every sensor $h, 1 \leq h \leq p$, let h_d be the set of items whose destination is sensor h . *The permutation routing problem* is to route the items in such a way that for all $h, 1 \leq h \leq p$, sensor h contains all the items in h_d . Consequently, each h_d must contain exactly n/p items (see Figure 1 for an example).

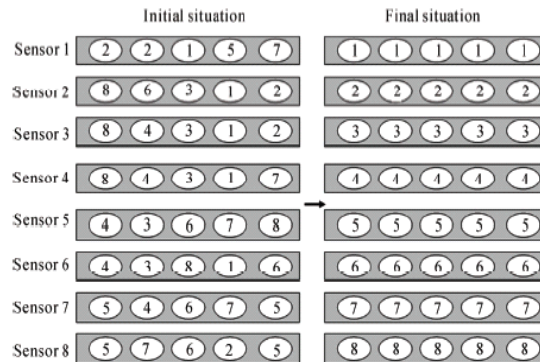


Figure 1. Permutation routing with $n=40$ and $p=8$.

2.1. A clustering scheme in cliques

Our approach uses one of the protocols from [17, 18] to partition network into clusters (cliques). The figure below illustrates a network in which each clique is a single hop sub-network.

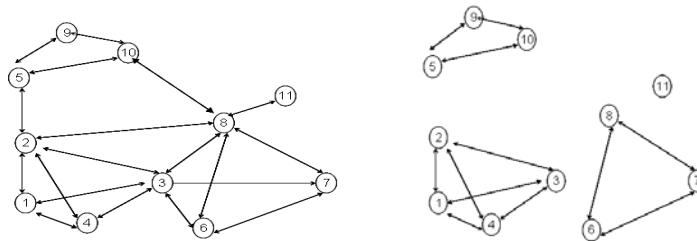


Figure 2. a: network with 13 sensors. Figure 2. b: Resulting cluster formation in cliques

2.2. Hierarchical Clustering

Banerjee and Khuller [2] proposed a clustering algorithm for multi-hop sensor networks.

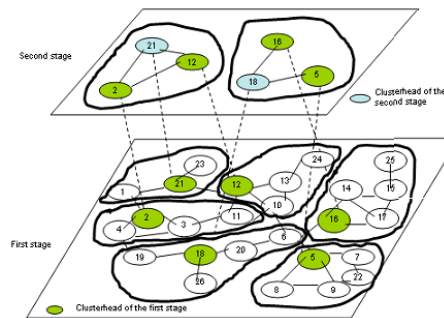


Figure 3. Hierarchical clustering with $k=3$

Their clustering scheme is motivated by the need to generate an applicable hierarchy for multi-hop wireless environment. Their method yields a multi-stage clustering. To reach their goal they construct a breath first search tree such that each level is composed of cluster heads of the immediate low level. These Clusters are by definition disjoint and the number of the nodes in a cluster remains between k and $2k$ for some integer k . Figure 3 shows a hierarchical clustering of a network of 25 sensors with $k=3$.

3. Efficient Permutation Routing Protocol in multi hop WSNs

We recall that we have p sensors and n data items saved in these p sensors. Hence each sensor has a locale memory of size $O(\frac{n}{p})$. The time is slotted

Our Approach providing a permutation routing in multi-hop sensor network consists of the following four phases:

3.1. Phase 1: Clustering procedure in cliques

The sensors run one of the protocols in [17, 18] to create cliques like clusters. We assume that this phase yields k cliques (clusters), hence k cluster heads named $CH_{\text{clique-}i}$ for the clusterhead of clique i . In fact clique i is a hub for its local sensors and will be named $HUB(i)$. Hereafter $CH_{\text{clique-}i}$ will be named $CH_{HUB(i)}$. The role of clusterhead $CH_{HUB(i)}$ is to collect all data items whose destination sensors are in i . Note HUB_{max} the clique that contains the maximum of sensors. Initially $HUB(i)$ may contain outgoing items i.e. items whose destinations are not in $HUB(i)$. Thus the goal of the phases that follow is to describe a mechanism that permit to each sensor to collect all its own data items.

3.2. Phase 2: Local Broadcasts in cliques

The idea of this phase is similar to the protocol *single-channel-routing* in [13]. The broadcast item here is a couple $(a(v), v)$ where $a(v)$ is the data item belonging to sensor v . It can be summarized as follows. $CH_{\text{clique-}i}$ invites each node of $HUB(i)$ to broadcast one by one the data items it holds. In each slot, the sensor whose identity matches the destination of the item being broadcast copies the item in its local memory. If no sensor of the clique is the destination of the broadcast data item then the sensor broadcasting keeps this data item and counts the number of these its *outgoing data items*. Note that the cluster head has the IDs of all the residents of its cluster. The broadcasts are carried out on cliques. So the clique with the great number of sensors should help to estimate the total broadcast rounds of this phase. At the end of this phase all data items that do not belong to the sensors of a clique are saved in the clique. The goal now is to route them to their final destinations.

Lemma 1: *Since HUB_{max} detains the maximum number of sensors, it should need the maximum number of broadcast rounds in this phase. Therefore this phase needs to $(n/p) \lceil HUB_{\text{max}} \rceil$ broadcast rounds. $\lceil HUB_{\text{max}} \rceil$ is the number of sensors in HUB_{max} . (see [13]).*

3.3. Phase 3: Hierarchical clustering

The clustering in cliques of the first phase gives k cliques, thus k clusterheads. Now we focus only on these clusterheads and consider a network, say G' , whose sensors reduce to these k clusterheads. Clearly $|G'|=k$. Partition this network as in subsection 3.2 using the hierarchical clustering such that each resulting cluster contains at least $\frac{k}{2}$ sensors and at most k sensors. Hence the partition will give only one cluster, and thus one clusterhead. This clusterhead knows the IDs of all residents of its cluster, i.e. the IDs of the other $k-1$ sensors (see figure 4).

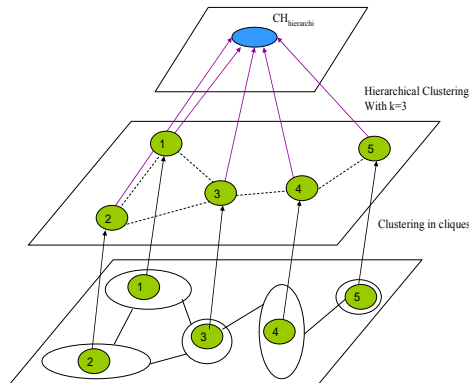


Figure 4. An example hybrid clustering: the first stage shows an example of clustering in cliques. The second stage shows the hierarchical clustering of G' .

3.4. Phase 4: Broadcastings the outgoing data items

Here we use of breath-first tree (BFS tree) created in the above sub-section on the hierarchical clustering. In this tree a node broadcasts simultaneously to its parents and children, and receives only from its parents or its children.

In this step the sensors whose cluster head is $CH_{hierarchi}$ (the root of the tree) are the first to broadcast their out-going data items as follows:

- (i). $CH_{hierarchi}$ invites its residents one by one to broadcast its outgoing-data items once every two slots. It collects this outgoing data and broadcasts it (in the next slot) in its turn to its sons on the BFS tree. The sons in their turn broadcast it till the leaves are reached.

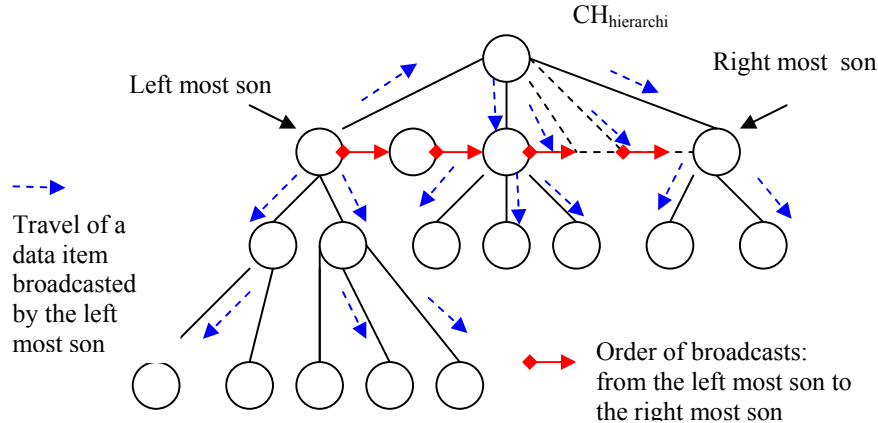


Figure 5. The orders of invitation of the sensors to broadcast and the way a broadcasted data travels trough the network.

- (ii). Next the left most son of $CH_{hierarchi}$ on the BFS tree is invited by its father to proceed as in (i) above. Its sons and $CH_{hierarchi}$ collect the broadcasted data item. $CH_{hierarchi}$ broadcasts it to the rest of its sons and its broadcast spreads till the leaves. The same procedure is carried out by the sons of the left most son of $CH_{hierarchi}$. And so on till all the left leaves are reached. This procedure is depicted in Figure 5.

On receiving a data item, a $CH_{HUB(i)}$ broadcasts it in its clique in the next slot. It is important to note that when a sensor of $CH_{HUB(i)}$ receives a data item it checks if it is its own. If it is the case it keeps it.

- (iii). After the last data item coming from the leaves of the left tree has been broadcasted to the right tree by $CH_{hierarchi}$, this later informs its right son to initiate the same procedures as in (ii) above

Lemma 1: *This phase $2n+6\log_2k$ are necessary in the worst case for the accomplishment of this phase.*

Proof. In the worst case all data items detained by each sensor are outgoing items. Therefore all sensors have to broadcast these outgoing items one every 2 slots. Thus $2n$ slots time are necessary. The last item coming from a leaf of the left tree has to travel to the root, i.e., $2\log_2k$ slot times. The last item coming from a leaf of the right tree has to travel to the root, and from the root to the leaves of the left tree i.e., $4\log_2k$ slot times.

The protocol is summarized by the pseudo code below:

Efficient Protocol-Permut-Routing- muti-hop-Wsn

INPUT: *wsn of p sensors in which a sensor may not have its own data items*

OUTPUT: *wsn in which each sensor has its own data items*

Begin

1. run the maximum clique formations protocol in [17 or 18] to obtain HUBS
2. in parallel on HUBS, run the protocol single-channel-routing of [13] for single hop wsn
3. run the hierarchical clustering algorithm in [2] with $k=|G'/2|$ on the dominating set, G' derived from 1.
4. //Broad casts of outgoing data Items//

4.1 Order sensors for broadcasting outgoing data items

4.2 broadcasts of the out going data items of each HUB

END

Theorem 1

Let p sensors in a multi-hop sensor network (n, p) with n items pretitled on it. Without clustering broadcast rounds, from lemma 1 lemma 2, the permutation routing problem can be solved in a multi

hop WSN in $n(2 + \frac{1}{p} \times |HUB_{max}|) + 6\log_2 k$ in the worst case.

$|HUB_{max}|$ is the number of sensors in the clique HUB_{max}

Remark: HUB_{max} being the clique containing the maximal number of sensors we have $|HUB_{max}| \leq n$.

Thus $\frac{1}{p} \times |HUB_{max}| \leq 1$. Therefore we have the following lemma.

Lemma 3: *Let p sensors in a multi-hop sensor network (n, p) with n items saved on it. Without clustering broadcast rounds the permutation routing problem can be solved in a multi hop WSN using a number of broadcast rounds not exceeding $3n + 6\log_2 k$ in the worst case.*

4. Experimental Results

We assume that nodes are static. The number of data items is fixed to 1000. We use C++ for the simulation. The condition for a network whether single-hop or multi-hop is the number of wireless links available. It is why we did our simulation with the condition on the number of channels. First we generate a random graph, and we count the average number of cliques that contain the maximum number of sensors and average number of cliques that contains the minimum number of sensors. Next we count the average number of corresponding broadcast rounds. Figure 6 shows the evolution curve of the average number of cliques with respect to the number of sensors. We see that the number of cliques is growing because we have a constant number of channels, and the probability for a new sensor for entering an existing clique is little.

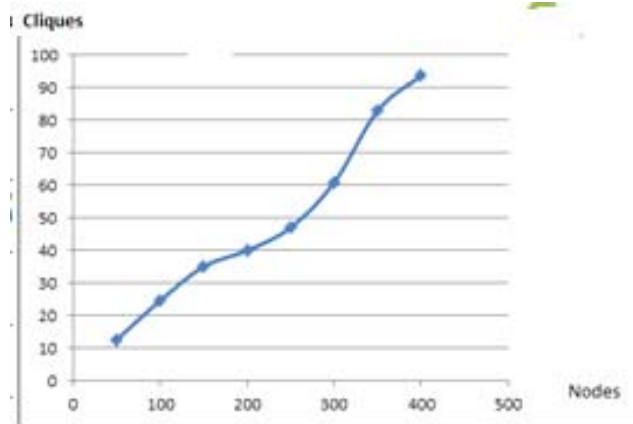


Figure 6. Average number of cliques

Figure 7 shows the evolution and the comparison curves of the average number of broadcast rounds with respect to the number of sensors. It shows that there is a significant gap between the protocol in [3] and our protocol, this is the result of using the new techniques.

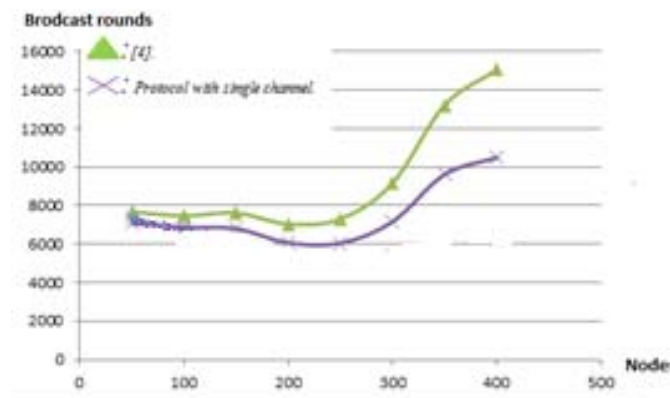


Figure7. Comparative curves of the average numbers of broadcast rounds

5. Conclusion

In this paper we presented a new protocol to solve the permutation routing problem with less broadcast rounds than one derived in [4]. More precisely we show that a permutation routing in a multi-hop WSN can be run in $3n + 6 \log_2 k$ in the worst case. It is better than the

$(k + 1)n + O\left(\left|HUB_{\max}\right| + k^2 + k\right)$ broadcast rounds performed by our former protocol in [3].

However some open problems remain. The derivation from the idea of this paper of a fault tolerant algorithm, which guarantees the delivery of data items to non-faulty nodes, is to be investigated. Also, the construction of an energy-efficient permutation routing protocol for multi-hop ad hoc network is a challenge. Other perspectives in this paper can be considered: in particular it should be interesting to see in the clustering technique in [10] can improve the number of broadcast rounds. Based on [11], is it possible to derive fault tolerant and energy efficient protocol from our work?

6. Acknowledgement

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7. References

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