Synchronized WSNs architecture for efficient remote tasks scheduling

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Abstract – **In this work a possible cooperation among Wireless Sensor Network (WSN)s has been investigated in order to enhance coverage capability of a WSN system and to improve service performance having the possibility to acquire information from Area of Interest (AoI) which is composed of some cluster area, which may belong to different WSNs. In particular, a sensor node that belongs to a specific cluster of a WSN can exploit other nodes to gather information through different WSN exploiting virtual connections that allow a Cluster Head (CH) to exploit clusters that may belong to external systems. For example if the service requires to acquire data from several areas or require to make some forecasting processing may be necessary to acquire data from neighbour areas thus allow us to exploit guest systems to acquire important information about environment or other kind of measurements. In order to perform these tasks it is important to design an efficient network protocol that address communications and synchronization issues among WSNs system. This can be made exploiting an ad-hoc protocol that synchronize WSNa and allowing remote job scheduling as well.**

I. INTRODUCTION

In this work, an efficient cooperation among WSNs system is investigated to increase system performances and coverages. In order to achieve cooperation we address Remote Task Scheduling (RTS) processes to allow local WSN to gather information also from other WSN or AoI. For example, it is possible that a particular measurement system need to know data from a far region that cannot be covered by sensors belonging to the own system, therefore, local sensor cluster has to recognize whole network asking for a remote measurement to acquire needed data. In particular, the main goal of this works is to demonstrate that a cooperative work among WSNs can enhance the whole performances of the system considering several applications fields such as monitoring, surveillance and measurements. Of course, an important issue to face is the synchronization among systems in order to schedule remote jobs. We are looking for an efficient mechanism that allow to synchronize jobs among several WSNs, if the synchronization process works well, this can assure that the achieved results are enough good and useful when they are sent back

to the sender of the request. Also in this work we propose two kind of approaches. In the centralized approach an eligible cluster head of the WSN has the task to distribute jobs remotely; In the distributed approach several entities are involved in the remote jobs scheduling spreading the management of the scheduling along the interested nodes. Both paradigms are based on the knowledge and message exchanged between WSNs CH. An architectural scheme of the proposed approach is better explained in further sections. This works is organized as herein described: In section II we present some of the related works describing in a brief manner the contents of the works; In section III we present the reference architecture that we consider in this work explaining as well as possible the main reasons that drove us to choose it. In section IV the used approach to solve the RTS problem is shown. In section V we present some brief results and at the last section conclusions and future works are presented.

II. RELATED WORKS

In this section there are many work that has been investigated in order to make a survey about the state of the art regarding the cooperative approaches and time synchronization in WSNs. In [1] , authors presented a survey of selected topics concerning development of wireless sensor network systems, from the point of view of time synchronization algorithms and proposed also a novel concept for time synchronization scheme. In [2], the authors proposed a new Mac layer scheme for WSN improving network reliability using cooperative communication. They mainly focused their work on a way to define a relay node among the neighbourhood of a node, efficiently with only few signaling messages. They proposed also a scheme based on an automatic forwarder selection and a link state evaluation in order to define the relay node. In [3], authors designed a Graph-based multi-hop cooperative Multiple Input Multiple Output (MIMO) transmission scheme.

It is aimed to optimize the network lifetime and saving energy for heterogeneous wireless sensor networks. In this scheme, clusters are established based on geographical position and the graph theory is applied to find an optimal forwarding path. Energy efficiency is one of most important develop goal for wireless sensor networks (WSNs). In [10], authors considered practical packet coding, rather than optimal random codebooks in
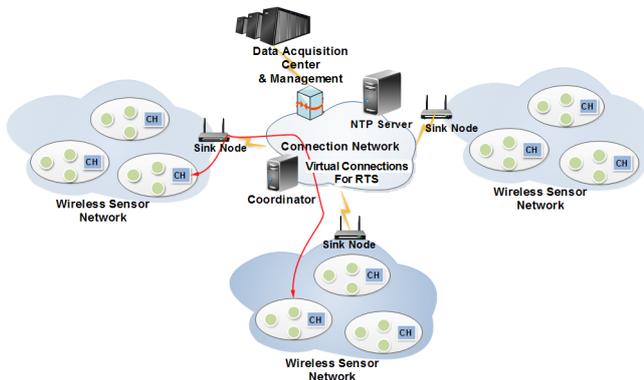
Fig. 1. Reference Architecture

an information-theoretic setting. The key contribution is the mechanism for power control, whose objective is to protect the primary users from a harmful secondary interference. In [11], [12] authors proposed two new routing protocol, based on Ad-Hoc on Demand Distance Vector protocol. The optimum route is chosen on the basis of the minimum perceived value of interference. In the first paper two distinct metrics are designed: the first one based on the global interference perceived by a node and the other one based on the link interference. In the second one, A new metric is also proposed, based on the maximization of the average SIR level of the connection between source and destination. In [13], authors proposed a multi-zone approach applied to the area monitored by sensor nodes. It tries to weight the info sensed by sensor on the basis of the distortion area in order to better estimate at sink node the event. In [6], authors proposed a heuristic to enhance cooperative detection of moving targets within a region that is monitored by a wireless sensor network. This heuristic is based on fuzzy dynamic weighted majority voting for decision fusion. In addition, they designed a finite state machine to mitigate the detection false alarm and to relieve the best time at which the cluster decisions should be reported to the sink. In [7], authors demonstrated that the potential performance improvement gained by using a routing metric that reflects the quality of links in terms of detection reliability. In addition, they derived the expression of such detection reliability-aware link metric considering a realistic multi-dimensional Gaussian autoregressive model to achieve information correlation within the monitored field. In [4], authors proposed an energy-efficient cooperative MIMO scheme, which combines energy-efficient LEACH protocol and cooperative MIMO. In this scheme, the network is divided to sectors with equal angle to reducing the distribution non-uniformity of cluster heads, but also can well balance the network load, save energy and increase the network lifetime. In [5], authors proposed a scheme to optimize the network lifetime and save energy for heterogeneous wireless sensor networks. This scheme

extends the LEACH protocol to enable the cooperative MIMO transmission between the sink and clusters. Based on the energy consumption model, the optimal parameter to minimize the overall energy consumption has been found. Using the adaptive selection of cooperative nodes and the cooperative MIMO transmission, this new protocol can obtain effective performance improvement in terms of the presence of node heterogeneity. In wireless communications, signal measurements are also very important when trying to tune a model parameter: for example in an underwater system [8] amplitude and signal fluctuations must be carefully measured, in order to take into account the dynamics of the acoustic channel. The same problem exists in cellular [14] systems, as shown by authors, where the wireless channel is subject to stochastic fluctuations that should be measured adequately, with a precise nodes coordination and synchronization. Also satellite communications are affected by synchronization problems [9], in fact the authors show how it is possible to enhance MF-TDMA switchings, caring about the accurate evaluation of the transmission rate. Regarding nodes synchronization interesting approaches consensus based are proposed in [15],[16], [17]. In particular, in [15] the dynamical clusterization of the WSN is proposed in nodes, which are involved in the measurement processes and nodes that are not involved is proposed in order to synchronize with high accuracy only the first ones and then prolonging the WSN lifetime. In the proposed approach the clusterization is made taking into account virtual connections among sensor clusters that belong to different WSNs.

III. REFERENCE ARCHITECTURE

In order to better understand the whole system first of all we need to introduce the reference architecture and the back-draw of the system. The growth of the networks and the importance of the WSN bring up several possibilities to realize new services improving the knowledge of the environments around us. Therefore, the needs to know more is driving us to measure a lot of parameters that will help us to do right choices when we have to face with a decisional maker issues. These knowledges can help us in several field of applications such as economic or technical decisions. Moreover, several kind of WSNs are going to take place and even more complex scenarios can be designed to improve our knowledge. In even more complex applications it is possible to realize cooperation between systems to design a more detailed applications that can pick up data remotely exploiting wide band connections among systems. In figure-1 a scenario example is illustrated. In this scenario, there are several WSNs where each one is designed to perform an own task. In this case we imagine to realize a monitoring system where a main cluster, placed into Data acquisition and management system, has to perform a decision maker process. In order to accom-

plish this task, it needs to know several parameters related to the environment involved into the system, but these parameters have to be collected from local and remote area as well. Main issue is how to bring up these data to take real time decisions, based on the knowledge of the environment. The CH belonging to the local WSN can ask for remote data acquisition exploiting other WSNs creating a virtual connections with a sensor node or CH that belongs to another WSN. The slave cluster that belongs to a remote system receive requests and check if it is possible to accomplish to the request scheduling the activities needed to gather data. In the reference architecture some important entities are defined, each system is composed of several clusters in each cluster a sensor node is elect as CH; each CH can communicate with sink nodes belonging to the same WSN. Moreover, in the reference architecture the Data Acquisition and Management Node (DAMN) has the main task to distribute and coordinate available services along the networks and it is chosen among the different CH of the sensors islands. For remote cooperation among WSNs we consider two kind of approaches, one is centralized and another one is distributed. More details about centralized and distributed approaches are given in dedicated section of this work.

A. Choosing the Data Acquisition and Management Node (DAMN) node in the network

The DAMN node is one of the most important node in the network for both centralized and distributed model. It aims to elaborate requests and manage data gathering among sensors systems. For these reasons the chosen node has to be the most robust, reliable and performing node. The choice is driven by some factors that we are going to explain but one of the most important is the energetic factors. Let us to recall that the nodes that compose the network compose a weighted and often undirected Graph where V is the set of the nodes composed of CH node only; let E be the set of the edges among CH, and $G(V,E)$ is the undirected graph representing network topology. In this scenario, considering nodes u and v where $u \in V$ and $v \in V$ the total energy consumption to send a data unit, between u,v along the shortest path, is indicated with $r(u,v)$, moreover, the distance between nodes is given by the term $d(u,v)$. Therefore the average cost of a generic node $c \in V$ is given by the following equation

$$cost(c) = \frac{1}{|V|} * \left[\sum_{x \in V/\{c\}} r(c,x) + \sum_{x \in V/\{c\}} d(c,x) \right] \quad (1)$$

The election process is based on the energy aware principle. Hence, the DAMN node is the node that requires the minimum average energy to send a data unit towards any node that belong to the system and that is enough closer to each node as well. This is summarized in the below equation:

$$cr = c \in V : \forall x \in V, c \neq x \Rightarrow cost(c) < cost(x) \quad (2)$$

IV. COOPERATIVE SYSTEMS

The main idea is to consider cooperative WSNs where several systems installations can exchange data covering those areas that are not possible to reach with a single system. Therefore, efficient network protocol and jobs scheduling have to be designed. In this scenario, it is possible to use wired and wireless connections in order to allow communications among systems reducing time and resources wasting as well. Moreover, in order to reduce delay we need to find better routes that are reliable and not congested among whole network, in order to reach this goal an efficient routing protocol has to be addressed. Routing protocol exploits all available connections in order to distribute in an efficient way network load avoiding overload, reducing delay and packet loss taking advantages of those links that guarantee a certain QoS level. Delay issues have to be addressed in order to achieve an optimal RTS and synchronizations. Achieved information are elaborated in distributed or centralized way. A more detailed analysis of RTS is given in next sections of this paper.

V. RTS

For some critical tasks a Master CH can mark as slave one or more CH to schedule jobs remotely, in this way master system has more resources to exploit in order to achieve a wide range of data also from remote areas. Moreover, it is important to implement a synchronized process in order to join remote data with local data. Each CH, sink nodes and DAMN start their activities performing a synchronization with a Network Time Protocol (NTP) server, which is reachable by all WSNs. After the synchronization, each system can start its own activities. If a slave remote cluster has to perform a task a authorization phase must be completed in order to allocate remotely time slots. Once the slave system has accomplished assigned tasks it sends data back. A remote system can be classified as Only Master (M), Master and Slave (MS) or Only Slave (S). In the table herein shown these three categories summarized:

Table 1. WSN system category

Category	Characteristics	Remote Jobs
M	Master	No
M/S	Master and Slave	if time slots are available
S	Slave	Yes

The WSN falls in the MS status when a remote WSN shares a set of time slot to its master in order to schedule external jobs. System falls in the S status when a system schedules all its available time slots to its master in order to perform external jobs. The S status can be enabled only
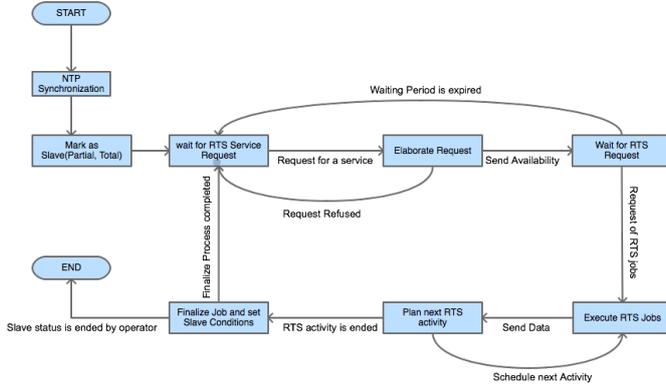
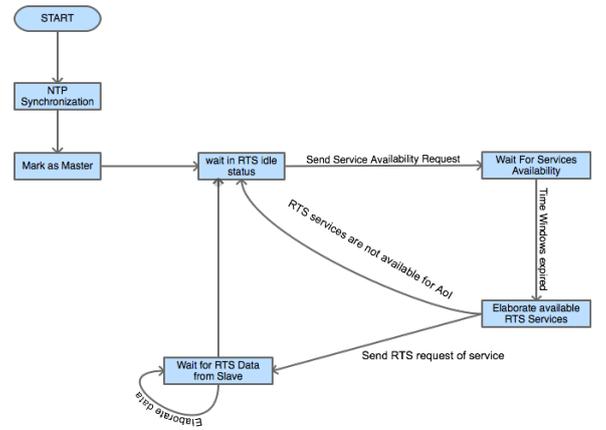*Fig. 2. Slave Remote Cluster flow chart in the distributed remote task assignment case*

Fig. 3. Master System flow chart in the distributed remote task assignment case

if the system is configured to accept external requests. If a system is marked as total slave shall not be possible to schedule internal tasks. In order to schedule other external tasks and to guaranty a job time, system cannot allocate other remote jobs until current activities are not finished. Moreover, master system can use one or more remote system to perform a RTS. A separate module is built to manage the RTS. This module has the main task to collect slave system data, which are coming from the network keeping systems synchronization. It belongs to the CH as well.

A. Centralized approach

When a CH asks for a RTS service it has to communicate space region to cover and time of coverage. An external entity, called DAMN also called coordinator, has the knowledge of the whole network, moreover, it knows the load of the networks and it can allow or reject requests for a remote services. This approach can be easier to implement but it can present some robustness issues because the coordinator node may be a bottleneck or a fault point for the whole system.

B. Distributed approach

In this approach the request are made in a distributed manner, however, a generic node has to ask in a direct manner for remote services to designed CH taking into account AoI and current load and availability. In this approach the network is more robust to failures and reliable but a more complex protocol has to be designed to allow data exchanging as well as synchronization issues have to take place. The entire processes are shown in figure-2 and in figure-3

C. RTS request Timing

In order to ask for a RTS job master system has to follow a specific timing sequence as shown in figure-4 and in figure-5 . The timing diagram for RTS service request is shown for both centralized and distributed approaches. Request acceptance is demanded to the slave system because the master does not know the actual status about load and current activities that slave is executing. In the centralized methods, instead, a central node called coordinator knows the load and the kind of services that slave can supply. Therefore, the request is sent only towards those system that can satisfy master request. The acceptance of a RTS service is also demanded to the slave that sends a message of acceptance towards the master and a busy message to the coordinator. Once the slave system sends its availability to make a RTS job then it waits for a limited time window that it is given by the following equation, if the time out expires the request shall be refused:

$$T_{win} = M_{STS} + cWin + \Delta_{RTS} \qquad (3)$$

Where:

Δ_{RTS} is the overall time needed to perform the RTS jobs and to transfer data to the master and it is given by the following equation:

- $\Delta_{RTS} = T_{ELAB} + \Delta_{RTT}$

- T_{ELAB} is the time needed by the slave system to perform data elaboration or data sampling;

- Δ_{RTT} is the RTT time to transfer data from master to slave;

M_{STS} is the timestamps of the Master system achieved when the master sends the RTS request. $cWin$ is the col-
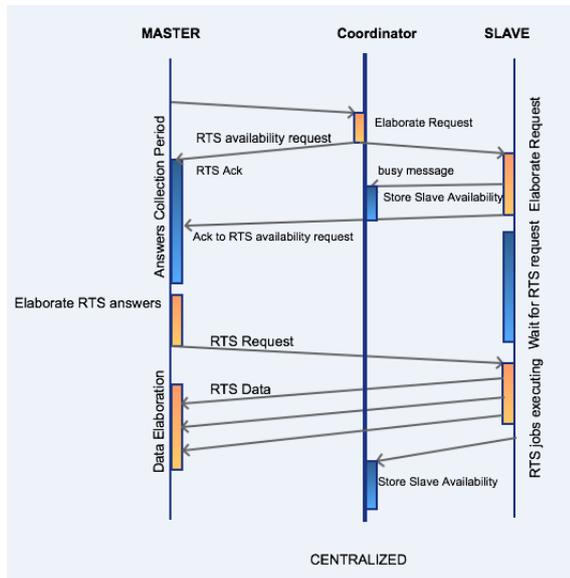
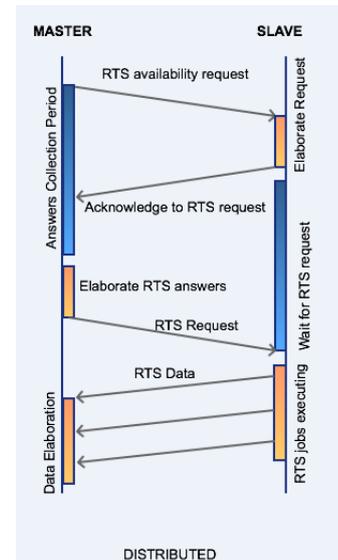*Fig. 4. Timing Diagram Centralized architecture*

Fig. 5. Timing Diagram Distributed architecture

lection time window used to store all the responses related to the RTS request.

VI. EXPECTED RESULTS

In this work we will focus on the system performances taking into account synchronization issues and time constraints also a brief analysis in terms of energetic consumption is proposed. It is also important to evaluate the impact of the remote scheduling on the goodness of the data gathering processes also measuring how the remote execution of some tasks improves system performances. In order to carry out these results we have already planned several simulation campaigns exploiting the OMNET++ plus castalia frameworks where the designed protocol shall take place.

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