Cluster-based Energy-efficient Composite Event Detection for Wireless Sensor Networks

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***Abstract*—Wireless sensor networks (WSNs), well known communicating architectures today, are often used to detect the occurrence of some environmental events, such as pollution monitoring, forest fires detection, location and tracking, etc. In order to reduce irrelevant alarms, multiple attributes are used in the event detection process. In WSNs, communication is often by far more expensive and difficult to control than local computation within nodes. Therefore, it becomes critical to reduce the amount of data exchange within a WSN, in order to optimize the use of power and energy resources within nodes. Energy optimization is thus one of the most important aspects of the WSN design. There are already literature and projects dealing with the detection of composite events using data aggregation at intermediate nodes. In this paper, a cluster-based energy-efficient composite event detection (CEC) for wireless sensor networks scheme is proposed, which performs local computation at sensor nodes and local data aggregation at level of each cluster heads in order to reduce the communication overhead. Simulation results show that jointly, considering both local computation at sensor nodes level and local data aggregation at intermediate nodes will further reduce the total energy consumption and thus prolong the network lifetime.**

Keywords-Wireless sensor networks (WSNs); data aggregation; local computation; composite event detection.

I. INTRODUCTION

A wireless sensor network (WSN) consists of a large number of sensor nodes which are distributed in a given space for measuring environmental parameters, such as temperature, light, sound, humidity, and so on [1]-[3]. Many applications have already been envisioned and described for WSNs in a wide range of areas, such as environment monitoring [4], health care applications [5], military surveillance applications [6], positioning and tracking [7], etc. Depending on the application domain, it may be necessary for sensor nodes within the WSN to react quickly or with critical timing constrains to detected events [8]. Moreover, the data collected by the WSN must be fresh when the corrective action is taken.

One of the critical tasks in designing a WSN is to monitor, detect and report various useful occurrence of events in a timely and reliable fashion. An event can be defined as an exceptional change in the environmental parameters. Events can be simple (atomic) or composite [9]. An atomic event can be detected merely based on the observation of one attribute, for example high temperature, if the temperature is higher than a specified threshold, an atomic event is detected. A composite event is the combination of different atomic events. A detailed description of composite events is given in Section III. An event alarming application needs an answer to a question which can be derived by a set of predicates. For example, in fire alarming applications, users are not interested in knowing the exact reading of attributes (temperature, smoke) of monitored area, but they want an exact and valid answer to the question: is there fire in the monitored area? In this case, we assume that an event has some significant characteristics that can be used as threshold to distinguish between normal and abnormal environment parameter. Event detection sensor networks require periodic data update (fresh data) from the network. Sending data periodically to a remote base station may incurs high communication overhead, and high energy consumption for event-driven applications. One of the key problems in event-driven applications is energy efficient data extraction, (i.e. how can a base station obtain the event report with a low energy consumption). Hill et al. [10] have shown that a sensor node spends approximately the same amount of energy for sending a single bit of data as it does to execute 800 instructions. Thus, in order to decrease energy consumption and thus increase network lifetime, the amount of data exchanged should be minimized.

Data aggregation techniques are very effective in reducing communication overhead (i.e., the data sensed by the sensors are combined at intermediate nodes before sending to a remote base station, BS). A number of data aggregation algorithms have been proposed in the literature [11]-[16]. Cluster-based topologies help to deal with in-network data aggregation (i.e., sensors are grouped in clusters and data aggregation is done locally within clusters). Some of the advantages to be achieved from clustering in WSNs are the reduction in energy for message transmission and constructing a virtual backbone for data routing purpose [17]. Many clustering algorithms have been proposed for WSNs, such

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as LEACH [18], LRS [19], PEGASIS [20], and HEED [21]. In this paper, we are not investigating clustering algorithms. We are considering that a wireless sensor network is divided into multiple clusters using an existing clustering algorithm. Each cluster has a special node (called cluster head (CH) or aggregator node) that collects data from all other nodes in the cluster and then performs some computations on the collected data. All CHs form the network backbone. Instead of transmitting each packet from sensor nodes to a remote base station, all CHs collect data, aggregate and send a single aggregated data packet to the base station along the network backbone. For intra-cluster communications (the communications between cluster members and the cluster head), an efficient routing mechanism is required. A number of routing protocols are reported in the literature [22]-[26]. Routing within the cluster can be realized through a directed diffusion algorithm.

Several schemes have been proposed for event detection for WSNs. In some studies, events are detected using a fuzzy logic rule-based system [27]-[28]. Several rules constitute a fuzzy rule-based system [29], however, keeping the rule-base might require a significant memory on sensor nodes. The number of rules grows exponentially to the number of variables, such as for n variables each of which can take m values, the number of rules in the rule-base is m^n. Furthermore, use of spatial and temporal features during decision process increases the number of rules. Since sensor nodes have limited memory, keeping a complete rule-base on every node might not be achievable. Moreover, constantly traversing a large rule-base might considerably slow down the event detection.

On the other hand, in several schemes, events are detected using a user defined threshold [30]-[32]. In such schemes, event alarm is arisen when sensor reading is lower or higher than predefined threshold value. However, existing threshold based schemes introduce high communication overhead. More details on related work are provided in Section II.

In this paper, we propose a threshold-based approach for composite event detection in WSNs. The main advantages of this proposed approach is simplicity, energy efficiency, and can be applied more easily. Indeed, the sensor node need to evaluate a simple boolean expression which is perfectly in line with considering requirement of WSNs of keeping computational complexity low. Our proposed Cluster-based Energy efficient Composite event detection (CEC) algorithm is a two-level event detection scheme. At the first level, sensor nodes perform local computation to detect atomic events and transmit a report message to the CH, when an atomic event has been observed. Moreover, the second level is carried out at intermediate nodes (i.e., CHs), which perform local data aggregation of received atomic event reports from the sensors in the cluster and take decision for a composite event. The main contributions of our proposed scheme are:

- (1) All sensor nodes (i.e., CHs and cluster members) send packets in binary format instead of raw data; achieves low overhead on data packet.
- (2) Each cluster member performs local computations on the sensed data, and sends a report message to the cluster head when an atomic event has been observed.
- (3) CHs perform local data aggregation for the received data from their cluster members and evaluate the composite event. Then, the CHs send particular synthesis of composite event occurrence to the base station, when a composite event has been observed.
- (4) Finally to reduce false alarm rate to the base station, composite event definition consists of multiple attributes [31].

Since events are often combination of more than one attribute , use of multiple attributes can help increasing event detection rate and reducing false alarm rate [31]. The event that is a combination of multiple attributes is a composite event. For example, the composite event fire is a combination of multiple attributes, i.e., the occurrence of fire should satisfy some conditions such as temperature $>$ 100 ^{0}C AND smoke $>$ 100mg/L, rather than a simple condition temperature $>$ 100 ^{0}C alone. Thus, it reduces false alarm rate to the base station.

In this paper, optimizing energy saving with joint local computation on sensors and local data aggregation on cluster heads is considered. Simulation results compare the proposed scheme with the non-local computation schemes. It is shown that significant energy saving can be achieved via the proposed scheme. Ongoing work further reviews performances and compare with other existing schemes; this will be presented in a companion paper.

The rest of the paper is organized as follows. In Section II, we describe related works. Section III provides detail of the Cluster-based Energy efficient Composite event detection (CEC) scheme. Section IV presents simulation results, and Section V concludes the paper and discusses future works.

II. RELATED WORKS

Recently, problems of event detection for WSNs have drawn a lot of attention. Liang and Wang [27] propose to use fuzzy logic with double sliding window for event detection. However, the authors do not study the effect of fuzzy logic approach.

Marin-Perianu and Havinga [28] have proposed fuzzy logic based approach for event detection. In this approach, fuzzy logic is used to combine personal and neighbors' observations for an event detection. However, the approach does not use any temporal semantics and do not analyze the number of false alarms.

Kumar et al. [30] have proposed a framework for detecting both simple and composite events with distributed collaboration of sensor nodes. This framework consists of two protocols called simple event detection and composite event

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detection. The proposed protocols are based on publish-subscribe communication paradigm. Each protocol works in two phases: (i) initialization phase, and (ii) collection phase. In the initialization phase, an application subscribes events of interest (atomic events or composite events) to the sensor network, and constructs an event based tree (EBT) based on these events. In the collection phase, data in the form of predicate is collected along this tree and sent to the subscriber. The subscriber will decide of the occurrence of events. In order to save energy, the data are collected using aggregation. In this scheme, all the sensor nodes periodically send their data to the subscriber. A conclusion is then made at the subscriber to decide whether a predefined event has happened based on the received data. However, sending data periodically from sensors to the subscriber incurs communication overhead which causes large energy consumption. In addition, at a subscriber, the received data need to be further analyzed to obtain a conclusion which delays the alarm to be timely announced.

Vu et al. [31] examined the Timely Energy-efficient k-watching Event Detection Problem. The objective is to assure that an area is monitored by at least k sensors. The proposed protocol divides the set of sensors into a number of non-disjoint subsets called detection sets such that each detection set ensures the k-watching property. Each detection set defines a tree, constructed using the Breadth First Search (BFS) algorithm starting from a gateway and data is then collected along this tree. Any sensor node with richer energy resource can be gateway. To ensures k-watching property, the protocol maintains a counter 'cl' to records the number of currently required sensors for composite event detection in the actual detection set. In this scheme, all the sensor nodes send their sensed data to a gateway node, and a decision on whether a predefined event occurs based on the received data is made by gateway node. However, sending sensed data from sensors to the gateway node incurs high communication overhead which causes large energy consumption. In addition, an other drawback of this approach is that it requires global information to construct the detection sets.

To overcome the problem of global information in [31], Marta et al. [32] have proposed an energy-efficient composite event detection in wireless sensor network. The algorithm sets sensor's schedule using a localized connected dominating set based approach. In the Initialize phase a sensor node will decide whether it will be active or sleeping in the next round. The algorithm decides the sensor scheduling at the beginning of each round. Each node relies on local information from its h-hop neighborhood. The main drawback of this approach is that each node requires h-hop neighborhood information. For constructing h-hop neighborhood, each node broadcasts h-HELLO messages, thus incurring high communication overhead.

III. COMPOSITE EVENT DETECTION

A composite event, e.g., fire is a combination of multiple attributes, i.e., the occurrence of fire should satisfy some conditions such as temperature $> 100\ ^0$C AND smoke $>$ 100mg/L AND humidity < 50. In particular, this paper focuses on forest fire detection. We implement threshold-based method for forest fire detection in WSNs. In forest fire detection method, sensor nodes collect measurement data such as , temperature, smoke, and relative humidity. All these factors are key factors for determining the forest fire [33]-[34]. The Forest-Fires Surveillance System (FFSS) [33] was developed to prevent forest fires in the South Korean Mountains and to have an early fire-alarm in real time. The system senses environment state such as temperature, humidity, smoke and determines forest-fires. It is quite difficult to maintain threshold values for temperature, smoke, and humidity. High temperature, low humidity are the key factors for forest fire [35]-[38] and burning of wood gives off large amount of smoke. We evaluate our approach by setting threshold value for temperature, smoke and humidity equals to 50, 50, and 20 respectively.

All nodes have sensors, temperature, smoke, and humidity. But due to lack of energy there might be a situation where sensor can fail, e.g., Node 1 has temperature, smoke and humidity sensors. But, node 2 has smoke and humidity sensors because temperature sensor on node 2 has failed. In such case, composite event detection must be occurs with sharing sensing capabilities of sensor nodes. Keeping this in mind, our approach perform composite event detection at cluster head. In this section, we present a Cluster-based Energy efficient Composite event detection (CEC) protocol for WSNs in detail.

A. Notations, Messages structure, and Preliminary definitions

*1) **Notations**:* The following notations are used throughout the paper for different type of messages used in our simulations.

- Thr_Temperature, Thr_Smoke, Thr_Humidity: Thresholds for temperature, smoke, and humidity respectively.
- C_Temperature, C_Smoke, C_Humidity: Current sensed temperature, smoke, and humidity respectively.
- AE: Atomic Event
- CE: Composite Event

*2) **Messages structure**:* A message has several fields. The first field of a message is the type of the message which can be one of the following: AE_Report (Atomic Event Report), and CE_Report (Composite Event Report).

- **AE_Report message has the following format:** {AE_Report, S_ID, (X_{S_ID}, Y_{S_ID}), Dest_ID, (X_{Dest_ID}, Y_{Dest_ID}), Temperature, Smoke, Humidity}
  Where, S_ID field stores the ID of the sensor node

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that sends the message (sender node), (X_{S_ID}, Y_{S_ID}) field stores the location of the sender node in the monitored area, Dest_ID field stores the ID of the destination, (X_{Dest_ID}, Y_{Dest_ID}) field stores the location of the destination, Temperature field holds the report of atomic event Temperature, Smoke field holds the report of atomic event Smoke, and Humidity field holds the report of atomic event Humidity. This message is used by ordinary nodes (cluster members) to give information on the occurrence of an atomic event to the CH in the cluster. The packet size is 132 bytes.

- **CE_Report message has the following format:** {CE_Report, S_ID, (X_{S_ID}, Y_{S_ID}), Dest_ID, (X_{Dest_ID}, Y_{Dest_ID}), CE}
  Where, S_ID field stores the ID of the sensor node that sends the message (sender node), (X_{S_ID}, Y_{S_ID}) field stores the location of the sender node in the monitored area, Dest_ID field stores the ID of the destination, (X_{Dest_ID}, Y_{Dest_ID}) field stores the location of the destination, and CE field holds the report of composite event. This message is used by CHs to give notification to the BS that the occurrence of a composite event has been detected. The packet size is 124 bytes.

*3) **Preliminary definitions**:* An atomic event condition and composite event condition are formalized as follows.

Definition 1 Atomic Event detection: An atomic event can be determined based on single attribute. The atomic event detection is carried out by comparing sensed data of attributes with their predefined threshold values. An atomic event condition is a Boolean formula and is denoted by AE which evaluates to TRUE or FALSE.

Definition 2 Composite Event detection: A composite event involves multiple attributes. A composite event condition is also a Boolean formula and is denoted by CE which occurs when all attributes that forms a composite event occurs.

B. Cluster-based Energy efficient Composite event detection (CEC) protocol

Our proposed CEC protocol contains also two phases: (1) Initialization phase and (2) data collection and composite event detection phase.

(1) Initialization phase: In initialization phase, clusters are formed after network deployment using an existing clustering algorithm. Clusters are assumed to have their own cluster head and all CHs collectively form a backbone in the network (shown as Figure 1.). CHs will send their report to the base station along the backbone. For simplicity of our discussion, we assume that each CH knows the topology and other ordinary nodes (cluster members) in each cluster know their CH. Note that the knowledge needed by CHs and cluster members can be obtained when the clustered network is built.

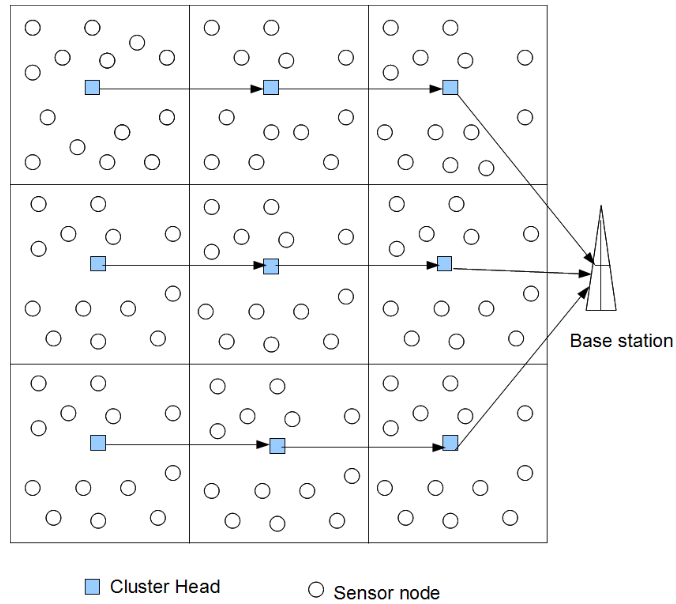

Figure 1. Clustered network

(2) Data collection and Composite Event detection phase: Each node periodically monitors a set of distributed attributes A = { A_1,...,A_n}, and generates a discrete data value vector at every time instance (at every second). Each attribute, A_i, may be an environmental property being sensed by the node (i.e., temperature, smoke, humidity). In this paper, sensor data is generated via a pseudorandom number generator. The node compare the sensed with their corresponding predefined threshold values, and compute atomic event 'AE' using the definition 1. When AE becomes "TRUE" (i.e., AE = 1), a cluster member sends <AE_Report> message to the CH in the cluster. We assume that CHs have timer. Timer is used to ensure that the composite event detection is based on fresh date received from cluster members. On receiving <AE_Report> message, CH performs local data aggregation to estimate composite event occurrence based on the collected data within the "timer" using the definition 2. When CE becomes "TRUE" (i.e., CE = 1), a cluster head sends <CE_Report> message to the BS along the network backbone.

IV. Simulation and Results

A. Simulator

WSNet simulator [39] is used as a simulation platform. WSNet is wireless network event-driven simulator, it has been developed in CITI laboratory of INSA Lyon. It is largely similar to other event-driven simulators such as ns2, JiST, GloMoSim, GTNetS, omnet++ though it differentiates itself with various functionalities, a precise radio medium

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simulation and the simulated node internals. Node, environment and radio medium blocks are developed in independent dynamic libraries. Moreover, the addition of new models does not require to modify the core of WSNet and can be done easily.

B. Simulation Results

We evaluate our approach composite event detection *with Local Computation* on the cluster members in the cluster through simulation, and we compare it to composite event detection *without Local Computation* on the cluster members in the cluster. The parameters involved in this comparison are number of messages transmitted in the cluster, and amount of the total remained energy in the cluster. To do simulation and evaluation, 100 sensor nodes are located randomly within a cluster of 50*50 m^2. The initial energy of nodes is taken 1 Joule. We consider that each node consumes 0.003 Joules to send a packet. Atomic event attributes are sensed periodically and in each period atomic event detection process is executed. All of the simulations were run 50 times, and the average results are plotted in the graphs. Table 1 lists the simulation parameters.

Table I
SUMMERY OF THE PARAMETERS USED IN THE SIMULATION EXPERIMENTS

Parameter	Value
Simulation time	10s,20s,30s,40s,50s,60s,70s,80s, 90s,100s
Cluster size (m x n)	50 x 50 m^2
Number of Nodes in the cluster	100 nodes
Nodes distribution	Nodes are randomly distributed
Performance parameters	Communication overhead within the cluster, sum of remaining energy in the cluster
Antenna type	Omnidirectional
MAC Layer	802.11
Initial node energy	1 Joule
Energy for transmitting one packet	0.003 Joules
Radio range	30

Figure 1 shows comparison of communication overhead in the cluster by varying simulation time for two cases. *NoLocalComputation* is the case of all existing protocols for composite event detection, in which all ordinary sensors monitor atomic event attributes and send it to the CH periodically. *CEC Scheme* is the case in which local computation for an atomic event detection on the ordinary sensors (cluster members) is applied. When a cluster member detects an atomic event, then it sends a message to the CH. Figure 1 shows that our proposed scheme has low communication overhead in the cluster when compared to the existing scheme with *NoLocalComputation*.
Figure 2 shows comparison of the total remaining energy

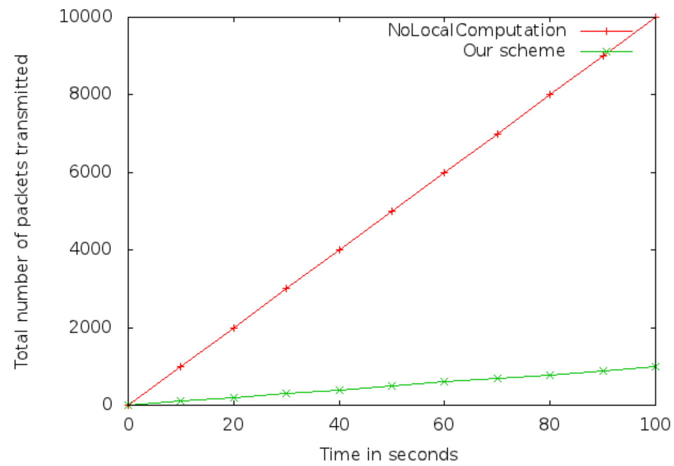

Figure 2. Total number of packets transmitted in one cluster

of cluster member in the cluster by varying simulation time in *CEC Scheme* to *NoLocalComputation* case.

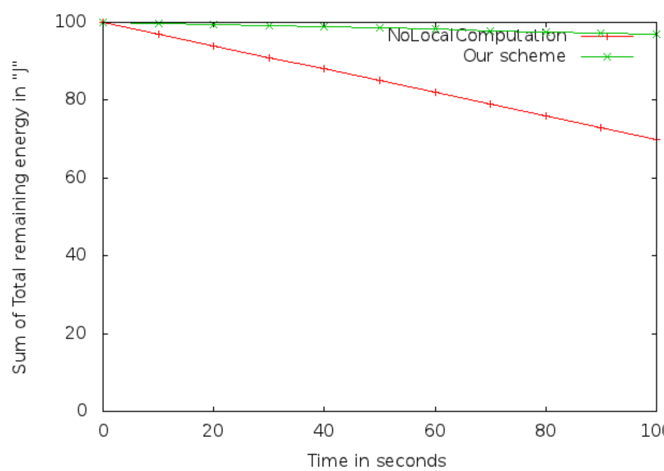

Figure 3. Total Remaining Energy in one cluster

V. CONCLUSION AND FUTURE WORK

As mentioned already, communication consumes high energy when compared to computation in WSNs. In order to reduce energy use within sensor nodes and thus to increase lifetime of wireless sensor networks, composite event detection with local data aggregation has been used in this work. It is supported by local computation in the clusters. Our proposed scheme is proven to be more efficient, since each sensor is required to perform local computation to detect the atomic event and send report to cluster head in the case when atomic event occurs. The total remaining energy in the cluster was also determined, which is considered as the metric to prove energy efficiency with our proposed protocol. This has been conducted by simulation. The simulation results show that using local computation in the

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cluster, communication overhead is decreased by our scheme and thus more energy is saved than the existing schemes with *NoLocalComputation* which will lead therefore to an increase the network lifetime.

In our ongoing work, we will examine the performance data, accuracy, robustness and reliability. To prevent false alarms, a computationally cheap and efficient filtering system is required for forest fire detection. Keeping into mind the critical resource constraint nature of sensor network, we use Bayesian classifier and Gaussian Mixture Model classifier to filter false or irrelevant event reports. The companion paper provides information about these classifiers and reasons why they are suitable for wireless sensor networks. We will compare our proposed approach with other existing schemes. Furthermore, filtering process has an impact on reporting delays. We will also investigate trade-off between irrelevant alarms tolerance and reporting latency.

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