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Real Time Approach for Data Placement in Wireless Sensor Networks

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Abstract—The issue of real-time and reliable report delivery is extremely important for taking effective decision in a real world mission critical Wireless Sensor Network (WSN) based application. The sensor data behaves differently in many ways from the data in traditional databases. WSNs need a mechanism to register, process queries, and disseminate data. In this paper we propose an architectural framework for data placement and management. We propose a reliable and real time approach for data placement and achieving data integrity using self organized sensor clusters. Instead of storing information in individual cluster heads as suggested in some protocols, in our architecture we suggest storing of information of all clusters within a cell in the corresponding base station. For data dissemination and action in the wireless sensor network we propose to use Action and Relay Stations (ARS). To reduce average energy dissipation of sensor nodes, the data is sent to the nearest ARS rather than base station. We have designed our architecture in such a way so as to achieve greater energy savings, enhanced availability and reliability.

Keywords—Cluster Head (CH), Data Reliability, Real Time Communication, Wireless Sensor Networks (WSN).

I. INTRODUCTION

WITH the advancement in technologies such as MEMS sensor devices, wireless networking, and low-power embedded processing, the dream of deploying large-scale sensor networks is fast becoming a reality.

Wireless Sensor Networks have recently received tremendous attention from both academia and industry because of its promise of a wide range of potential applications in both civil and military areas. WSN hold great promises in providing a new networking paradigm, which allows for interacting with the physical world.

Though each individual sensor may have severe resource constraints in terms of energy, memory, communication and computation capabilities, thousands or even hundreds of thousands of them may collectively monitor the physical world, disseminate information upon critical environmental events, and process the information on the fly [1], [2]. The WSN can prove useful in the coordination and planning of emergency and disaster relief operations e.g. fire, earthquake, terrorist attack. As the application domains of WSN are getting gradually wider, higher real time characteristics in applications and platforms are required, such as in military applications. In such systems, deadline violations that can occur in processing or transmission of collected data may result some catastrophic events.

Due to the necessity of timeliness of computing in some of WSN applications, many valuable researches on real-time communications, power management and task scheduling have been done. In WSN depending on the application there may be a need to rapidly respond to sensor input. For instance, in a fire handling application, actions should be initiated on the event area as soon as possible. Moreover, the collected and delivered sensor data must still be valid at the time of action. Thus the issue of real-time communication is very important in WSN.

Although several real time protocols have been proposed for mobile ad-hoc networks; due to differences between ad-hoc networks and WSN, it is not suitable to directly transplant those protocols into the design of WSN. In the large-scale sensor networks data integrity and reliability in addition to real time communication is also an issue. The reliability of data is crucial to take an effective decision. The resource constraint of each node in terms of energy, computation and memory, and potentially frequent node failures – all present formidable challenges.

Accessing and processing data produced in a wireless sensor network using a database-like approach [3]–[5] has several advantages. Sensors can be deployed in the physical environment and applications that manipulate their data can be created, refined, and modified afterwards without any physical intervention on the sensors themselves.

The data management activity performed in the network can be remotely controlled by interactively issuing queries, expressed in a high level language, which specify what data are of interest for a certain task, and how they should be manipulated. In this paper we propose an architectural framework for reliable and real time placement and dissemination of data in wireless sensor networks.

The rest of the paper is organized as follows. Section 2 introduces the related work. Section 3 explains the various design issues. Section 4 exposes the Architectural framework. Section 5 defines the system structure. Section 6 describes the performance evaluation.

II. RELATED WORK

SPEED [6] and RAP [7] are two proposals providing real-time data delivery services in sensor networks. They are based on an idealized model that takes into account both the remaining lifetime before a data report expires and the remaining distance the report has to travel. Given the physical

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distance to the destination and the lifetime of a packet, a desired velocity can be calculated. If the packet travels along a straight line towards the destination at desired speed it will not miss the deadline. They both use greedy geographical forwarding, but differ in the exact mechanism used.

In RAP, the required velocity is updated at each hop to reflect the urgency of the report. A node uses multiple FIFO queues with different priorities to schedule reports of varying degrees of urgency. Each queue accepts reports of velocities within a certain range. RAP further adjusts the waiting and back-off times at MAC layer based on the priority of the report being transmitted, so that one with higher priority has greater probability of accessing the channel.

SPEED is an adaptive, location-based real-time routing protocol, which can be effectively used if the location information is available in all sensor nodes and the location updates can be delivered to the source sensors regularly. In SPEED, a node actively controls the data rate to avoid congestion by maintaining a relatively stable relay-speed to each neighbor.

The node measures the delay of sending a report to each neighbor using exponential weighted moving average. Given a report with velocity v to be maintained across the sensor network, it computes the speed v_i of the report, if neighbor N_i is chosen as the next hop. It chooses one neighbor from the group of neighbors with $v_i > v$ to forward the report to the next node. If no such neighbor exists, the report is forwarded to the next node with some probability. Nodes in a congested region also feedback back-pressure messages upstream, so that data are detoured to bypass the region.

III. DESIGN ISSUES

A typical sensor network operates in five phases: the planning phase, deployment phase, post-deployment phase, operation phase and post-operation phase. In the planning phase, a site survey is conducted to evaluate deployment environment and conditions, and then to select a suitable deployment mechanism. In the deployment phase, sensors are randomly deployed over a target region. In the post-deployment phase, the sensor networks operators need to identify or estimate the location of sensors and to access coverage. The operation phase involves the normal operation of monitoring tasks where sensors observe the environment and generate data. The post-operation phase involves shutting down and preserving the sensors by settings the sensors to sleep mode for future operations or destroying the sensor network.

In a WSN setup, the nodes may be deployed in an ad-hoc manner with no predefined topology. The nodes automatically setup a network by communicating with one another in a multihop fashion. New nodes can malfunction, be added or removed from the network at any time. Newly added nodes must integrate into the network seamlessly and the network must detect and react quickly when nodes are removed to avoid affecting the reliability of message delivery services.

The timely detection, processing, and delivery of information are indispensable requirements in a real-time WSN application. In SPEED there are three types of communication associated with data delivery

- unicast (a specific node will receive the packet)
- area-multicast (where a copy of the packet is send to every node inside the specified area)
- area-unicast (copy of the packet is sent to at least one node inside the specified area)

For efficient communication both the route discovery cost and resulting route length are important. Unlike wired networks, where the delay is independent of the route length, in multihop wireless sensor networks, the end-to-end delay depends on not only single hop delay, but also on the distance a packet travels.

Any real time protocol should satisfy three design objectives – stateless nodes, load balanced routes and congestion control mechanism.

IV. ARCHITECTURAL FRAMEWORK

WSN extends our capability to explore, monitor and control the physical world. Each sensor monitors, collects and generates real-time data stream about its environment. The sensor data behaves differently in many ways from the data in traditional databases. We also need a mechanism to register, process queries, and disseminate data over wireless sensor networks.

The proposed architectural framework for data placement strategy is real time, reliable and distributed. It supports basic kind of data integrity and disaster management approaches for wireless sensor networks [8], [9]. The main design paradigms in our architectural framework are discussed below.Cluster ManagementThe clustering has proven to be an effective approach for organizing the network into a connected hierarchy. Clustering sensors into groups, so that sensors communicate information only to cluster-heads (CH) and then the cluster-heads communicate the aggregated information to the processing centre, will save energy. Cluster-heads are responsible for coordination among the nodes within their clusters. Fig. 1 gives various components of a cell consisting of several clusters.

The entire operation is divided into rounds, where each round consists of a setup and data communication phase. In setup phase, clusters are formed using a distributed algorithm, where nodes take autonomous decisions without any centralized control. In data communication phase, data is gathered in the CHs from their cluster nodes and routed to the base station via ARS. The data from CH is routed to base station through multihoping by CHs.

Each node within a cluster autonomously decides if it will be the CH for the next round [10], [11]. In order to determine the eligibility to be a CH, each node i generates a random number between 0 and 1. If the number is less than a variable threshold T(i), the node becomes a CH for the current round r. Besides, a node's residual energy $E_{residual}$ could also be taken into consideration. Using (1) the threshold is calculated.

$$T(i) = \max\left(\frac{p}{1 - p(r \bmod \frac{1}{p})} \times \frac{E_{residual}}{E_{\max}}, T_{\min} \right) \forall i \in G$$

$$T(i) = 0 \forall i \notin G \qquad (1)$$

In (1) p is the desired CH probability, E_{max} is a reference maximum energy, T_{min} is a minimum threshold (to avoid a very unlikely possibility when $E_{residual}$ is small) and G is the set of nodes that have not been CHs in the last $1/p$ rounds. When a CH has been self-elected, it advertises itself as the CH to the neighboring nodes within its radio range.

To further improve energy efficiency we can use more than one level of clustering. Assume that there are k levels in the clustering hierarchy with level 1 being the lowest level and level k being the highest. In this clustered environment, the sensors communicate the gathered data to level 1 cluster-heads (CHs). The level 1 CHs aggregate this data and communicate the aggregated data or estimates based on the aggregated data to level 2 CHs and so on. Finally, the level k CHs communicate the aggregated data or estimates based on this aggregated data to the Action and Relay Station (ARS).

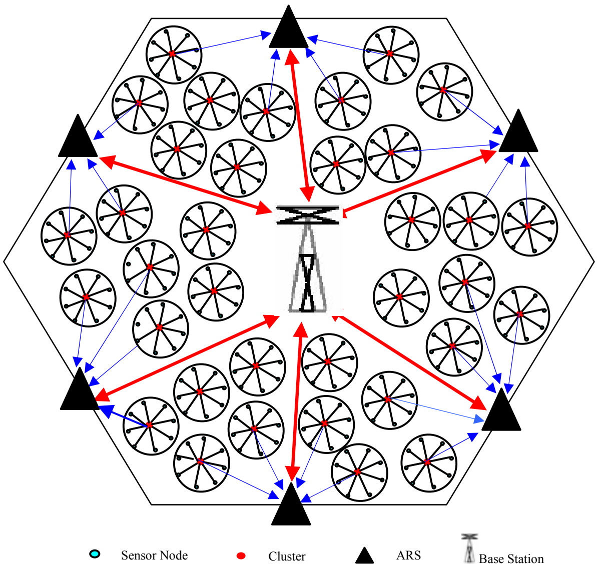

Fig. 1 Various components of a cell

A. Sensor-ARS Coordination

In order to provide effective sensing and acting, coordination mechanisms are required among sensors and ARS. Moreover to perform right and timely actions, sensor data must be valid at the time of action. The sensors detecting a phenomenon transmit their data to the ARS which processes all incoming data. It stores the received data in base station nodes and also sends the data to sink nodes via other ARS.

Depending upon urgency the ARS can initiate more reliable action after obtaining the integrated data from the base station. It can also collaborate with other ARS to have more reliable knowledge about the overall event. ARS are resource rich nodes with high transmission power; therefore ARS-ARS communication can be long range.

B. Node Placement

In many monitoring applications, sensor data is highly spatial in its nature. It requires correlating the data with the location of the data source in order to interpret the data in a meaningful way. The node placement in harsh isolated environments like target tracking and surveillance, must be flexible, low-cost, durable, and self-sustaining over long periods of time. Moreover multiple sensors must be deployed in the localized areas. The sensor nodes may be of several types. Therefore in sensor networks location is more important than a specific node's ID.

Because of constraints on the cost and size of sensors, energy consumption, implementation environment (e.g., GPS is not accessible in some environments) and the deployment of sensors, the base station and ARS will have known location information and their locations will be obtained by using a global positioning system (GPS). The cluster head nodes will obtain their location information by exchanging information with their respective ARS and Base Station. The other sensor nodes will determine their location information by using polar coordinates(r,θ) with respect to their respective cluster heads as the origin of the coordinate system (0,0).

C. Localization Methods

We can find transceiver's position on 2D area by knowing distances from three points (x_1, y_1), (x_2, y_2) and (x_3, y_3) where x_1, y_1, x_2, y_2, x_3 and y_3 are known [12]. As shown in Fig. 2 if we have three known points $A(x_1, y_1)$, $B(x_2, y_2)$, $C(x_3, y_3)$ and we know that point $P(x, y)$ is at a distance d_1, d_2, d_3 from these points respectively, we can find x and y.

Methods of estimating distances are generally related to circumstances of signal propagation. Two main parameters are attenuation and delay. If signal with power P_0 is sent at t_0, then the received signal power is

$$P_1 = \frac{P_0}{d_1^m} \qquad (2)$$

and is delayed by t_1 where

$$t_1 = \frac{d_1}{v} \qquad (3)$$

In (2) and (3) d_1 is a distance between two points, m is a constant that depends on environment and v is a speed of a signal propagation in this environment. As we see both parameters can be used to estimate distance d_1.

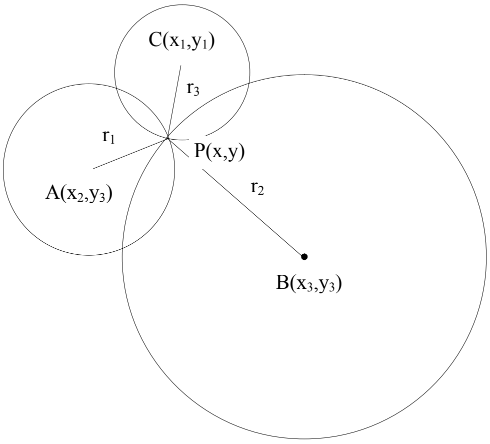

Fig. 2 Finding point's position knowing distance to three known points

Using Time of Arrival (ToA) [13]–[16] and Time Difference of Arrival (TDoA) algorithms [17], [18] we compute distances between point *P* (which position we are looking for) and each receiver (which positions are known).

Unlike ToA and TDoA, RSS algorithm bases not on signal delay but on signal strength analysis [15], [19]. If the transmitted signal strength P_0 is known, distance between sensors can be estimated by measuring received signal strength P_1 using (4).

$$d_1 = m\sqrt{\frac{P_0}{P_1}} \tag{4}$$

One of the design optimization strategies is to deterministically place the sensor nodes in order to meet the desired performance goals; optimal node placement is a very challenging problem. The position of nodes has a dramatic impact on the effectiveness of the WSN and the efficiency of its operation. The nodes' positions affect numerous network performance metrics such as energy consumption, delay and throughput. For example, large distances between nodes weaken the communication links, lower the throughput and increase energy consumption.

D. Addressing Scheme

The addressing scheme in traditional networks is fixed x-y coordinate address. In our proposed architecture addressing format is <Location ID, Node Type ID>. The Location ID identifies the location of a node that conducts sensing activities in a specified region of the network. The Node Type ID describes the functionality of the node. We can utilize Location ID to make localized routing decisions. In a pure localized algorithm action invoked by a node should not affect the system as a whole.

E. Data Routing

In general data is routed among various components of our architecture by single hop or by multihop. To reduce average energy dissipation of sensor nodes, we send data to the nearest ARS rather than base station. And energy is distributed over the sensor network by keeping multihop routing from cluster heads to the nearest ARS. The [20] proposed a method based on location awareness to optimize route discovery by minimizing energy consumption. If Q is the minimum energy required to transmit a packet across a zone, a head node while initiating route discovery can broadcast a packet with an energy E ($Q \leq E < 2Q$) to ensure that response is received from its neighboring clusters. A receiving head in the neighboring area responds by sending its polar coordinates (r,θ) to the initiating head.

In the proposed architecture, CH will send the data to the nearest ARS. The ARS will then send the received data to the base station. Before sending data to the base station, the ARS will check current status of the base station. The data will not be sent to it if the current status of the base station is collapsed; so that precious bandwidth is not wasted.

In sensor networks, the bandwidth and energy are scarce resources compared to a wired network. Therefore we suggest utilization of several simultaneous paths to carry packets from the source to destination. When a route becomes congested, we can use rerouting schemes [6] to reroute packets around large delay links with minimum control overhead.

F. Data Storage

In wireless sensor network individual identity of nodes is almost always unimportant. For storing information, as suggested in [21]–[23] we use data centric storage. In data centric storage, data can be stored and retrieved by name. Therefore in data centric storage for sensor network, the communication primitive are organized around the sensed data instead of network nodes which is normally the case in wired or conventional wireless networks.

Data centric communication relies on naming the data. Naming the data enables nodes within the network to store or cache the data transparently. In [24] authors have given a novel idea for storing data at a node, which has been generated at another node according to the name of data. We propose to use same concept for our architecture.

Data centric storage also enables use of indices or keys for efficient access to data in large-scale sensor networks. Using data centric storage mechanism in our architecture, the cost of accessing events for example, aggregation of observations generated by various sensor nodes will be almost zero since all events will be available at one node (base station). Further to speed up the storage and retrieval of data we can use some hashing mechanism.

Instead of storing information in individual CH as suggested in some protocols, in our architecture we suggest storing of information of all clusters within a cell in the corresponding base station. Therefore in our architecture data integrity problem can be handled in more controlled and centralized manner.

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G. Distributed Storage & Replication

To further enhance the availability the information stored in a base station is also replicated in the adjacent base stations; so that if a base station collapses due to disaster the ARS can obtain the required information from elsewhere. Fig. 3 shows the structure of a sensor network where base stations are in the centre and ARSs are at the boundary of the cell.

Each base station stores data relevant to its environment in a distributed fashion. The distributed architecture results in enhanced availability and speedup of query processing. Also the collapse of a single base station will result in the loss of the fraction of overall system information.

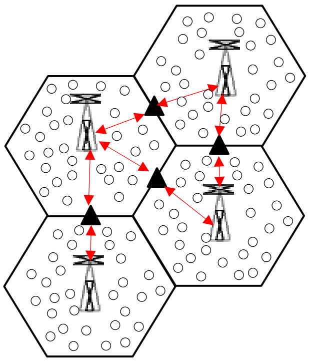

Fig. 3 Cellular Network Framework

H. Retention Period

The data volume can overload the limited storage and communication capacity of a sensor network. It is impractical to store a large volume of raw data locally at the data sources or to transmit the data over the sensor network to a central depository [23], [25]. Therefore the retention period for the data to be stored in the base station is a very important parameter. The choice of right value for this parameter is very important because this parameter will control the amount of data to be stored locally.

After the retention period is over the irrelevant data should be removed from the base station, so that base station does not go out of memory. We can also use some compressing techniques to further reduce the memory requirement to store the data.

I. Query Optimization

For interaction with a sensor network as a relation database we propose to use the approach suggested in [26]. Defining a query for the query processor means defining what activities must be carried out by each sensor in the network. We can specify a query in an SQL-like language for example MW-SQL [26]. A query is represented as a combination of operators of the query algebra connected by the data streams. The MW-SQL queries are expressed through query statements having the form:

SELECT select-list

FROM source

[**WHERE** condition]

[**EPOCH** samples [**SAMPLES**]]

[**EVERY** rate]

where keywords are represented in boldface.

The difference in cost (in terms of evaluation time) between a good strategy and a bad strategy is often significant, and may be several orders of magnitude. Hence, it is worthwhile for the system to spend considerable time on the selection of a good strategy for processing a query, even if the query is executed only once. Various aspects for selecting an efficient strategy for processing the received query can be: choosing the right algorithm to use for executing an operation, and choosing the specific indices to use.

The base station may further achieve energy efficiency during query processing by sending filtered or average of the sensed data obtained as a query result instead of sending large amount of raw records over the network. The base station may also ignore results that are outside some predefined threshold limits as specified by the sink. It may process the obtained data and send the results to ARS. This could depend upon specific application requirements; for example, a requirement could be to obtain temperature of a particular region.

V. SYSTEM STRUCTURE

Our architecture is portioned into modules each of which deals with various responsibilities of the overall system. Fig. 4 shows these components and the connections among them.

A. Sensor Node

Sensors nodes are low-cost, low-power devices with limited sensing, computation and wireless communication capabilities. A sensor node consists of five basic components: a sensing unit, a processing unit, a power unit, ADC and a transceiver unit. Additional components such as power generator, global positioning system, and a location finding unit can also be attached depending upon the application.

The sensing unit observes phenomena such as thermal, optics or acoustics event. The processing unit is equipped with small memory, manages the work of other components; it is responsible for information communication, and also supervises eventual collaboration of the node with other nodes in accomplishing assigned sensing task. So it is important for our routing algorithm to have small computation time and small memory requirements.

The transceiver unit connects the node to the network. Each sensor node can have Node type ID that describes the functionality of the node.

B. Base Station

The base stations are responsible for data storage in a distributed real time database framework. The ARS lying on each pair of shared edges along the border between two cells passes the observations received from various CHs to the base stations of both the cells. In case, the base station receives redundant information it is ignored by it.

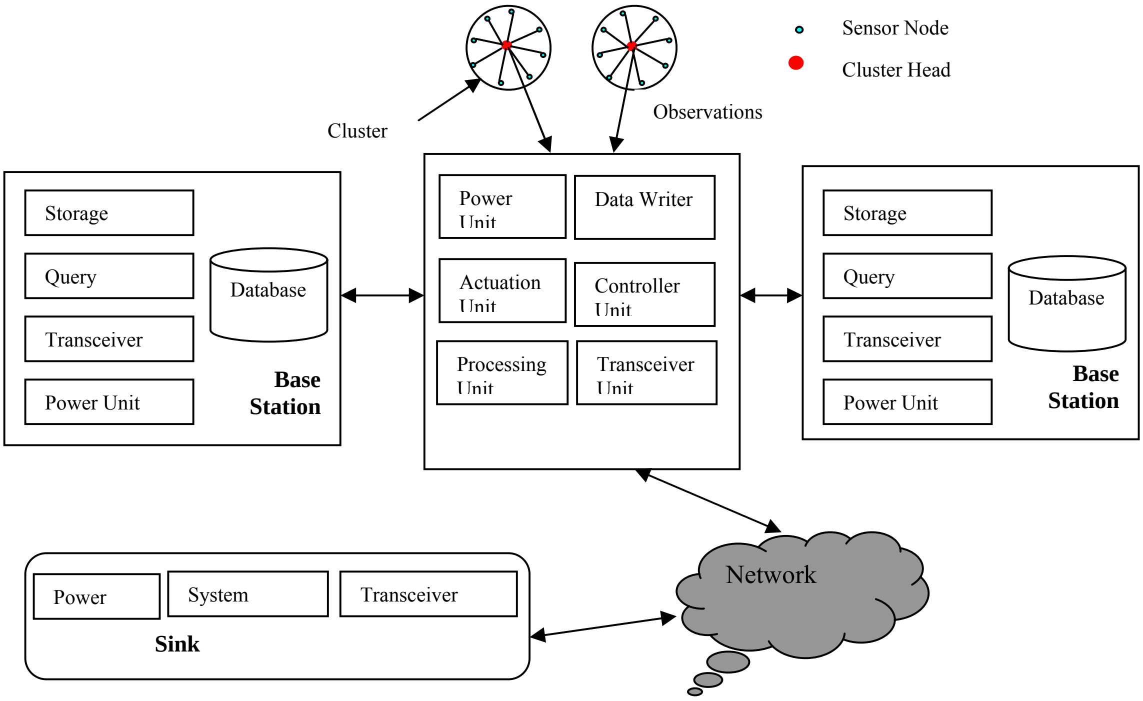

Fig. 4 System Structure

The main purpose of storing the entire information of the cell in the base station is that better data integrity can be achieved as ARS need not spend time on data aggregation before taking an effective decision.

The main advantage of replication is that in case due to some severe disaster some base station collapses. The ARS can obtain the information from the adjacent cell's base station. Our main aim is to prevent the collapse of the communication system.

The functional components of the base station can be broadly divided into storage manager component, query processor component, transceiver unit and power unit. The storage manager component provides the interface between the low level data stored in the database and queries submitted to the system. Its main goal is to simplify and facilitate access to data. The storage manager component may include authorization and integrity manager, file manager, buffer manager etc. The query manager component handles queries received from ARSs; it may further include DML compiler, metadata manager, query evaluation engine etc.

C. Action and Relay Station

The ARS are resource rich nodes equipped with better processing capabilities, higher transmission powers and longer battery life. The ARS nodes are placed on the bordering areas of cells and are responsible for data dissemination in a time efficient manner. An ARS unit consists of six basic components: an actuation unit, a processing unit, controller (decision unit), data writer, a power unit, and a transceiver unit.

The decision unit functions as an entity that takes sensor readings as input and generates action commands as output. These action commands are then converted to analog signals and transformed into actions via the actuation unit.

The ARS nodes are placed on each pair of shared edges along the border between two cells. The total number of seed ARS nodes needed for a N-cell system are computed using (5).

$$3N - \left\lfloor \sqrt{N} - 4 \right\rfloor \tag{5}$$

Every ARS supports two types of interfaces: *ad-hoc relay interface* and *cellular interface*. By ad-hoc interface, ARS may communicate with other ARSs and sink nodes. It uses cellular interface to communicate with base stations of cellular network.

During disaster any ARS may be collapsed. But there is little chance of collapsing all ARSs of a cell. Only one ARS is enough to convey data from sensor network of a cell to a base station. The data writer component of ARS can pass the information received from various CHs of WSN immediately to the corresponding base stations or it may store the information received in its local buffer and after some time send the combined information to further conserve power and communication bandwidth.

D. Sink

The sink acts as a bridge between the wireless sensor network and the physical world. The sink supervises and synchronizes the working of various components of WSN. It reports the critical findings; so that in case of some disaster or any other eventuality help from outside can reach the reported event area quickly. It monitors the entire wireless network systems and depending upon the feedback it sets the value of various controlling parameters like retention period etc. The sink will also specify the positions of nonfunctioning sensor nodes, ARSs or base station that will help in their replacement.

VI. PERFORMANCE EVALUATION

The performance is measured by average energy dissipation, system lifetime, successful data delivery and number of live nodes. To improve the longevity of the system it may be desired that only minimal set of sensors sense and report the environment. It is expected that our architecture will achieve greater energy savings, enhanced availability and fault tolerance. The scalability is very easy to achieve is our architecture and it will prolong network operation lifetime.

We assume that the sensor nodes are aware of their locations in their deployment area, and they are time synchronized. To do the analysis of energy dissipation we propose to use the model discussed in [27]. The transmission and receiving energy costs for the transfer of k-bit data message between two nodes separated by distance of r meters is given by (6) and (7) respectively.

$$E_T(k,r) = E_{Tx}k + E_{amp}(r)k \tag{6}$$

$$E_R(k) = E_{Rx}k \tag{7}$$

In (6) $E_T(k,r)$ denotes the total energy dissipated in the transmitter of the source node, and $E_R(k)$ in (7) represents the energy cost incurred in the receiver of the destination node. The parameters E_{Tx} and E_{Rx} in (6) and (7) are the per bit energy dissipations for transmission and reception respectively. $E_{amp}(r)$ is the energy required by the transmit amplifier to maintain an acceptable signal-to-noise ratio in order to transfer data messages reliably.

REFERENCES

[1] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, “Wireless sensor networks: A survey,” *Computer Networks*, vol. 38 Issue 4, 2002, pp. 393-422.

[2] C. Jone, K. Sivalingam, P. Agrawal and J. Chen, “A survey of energy efficient network protocols for wireless networks,” *Journal of Wireless Networks*, Kluwer Academic Publishers, vol. 7, 2001, pp. 343-358.

[3] S. Madden, M. J. Franklin, J. M. Hellerstein, and W. Hong, "The design of an acquisitional query processor for sensor networks", Proc. of the 2003 ACM SIGMOD Int. Conf. on Management of Data, 2003, pp. 491-502.

[4] S. Madden, M. J. Franklin, J. M. Hellerstein, and W. Hong, "TAG: a tiny aggregation service for ad-hoc sensor networks", Proc. of the 5th symposium on Operating Systems Design and Implementation, vol. 36, 2002, pp. 131 – 146.

[5] Y. Yao and J. E. Gehrke, "The Cougar approach to in-network query processing in sensor networks", *ACM Sigmod Record*, vol. 31, no. 3. Sept. 2002.

[6] T. He, J.A. Stankovic, C. Lu, T. Abdelzaher. “SPEED: A stateless protocol for real-time communication in sensor networks.” Proc. of 23rd Int. Conf. on Distributed Computing Systems (ICDCS'03), Providence, Rhode Island, USA, May, 2003.

[7] C. Lu, B. M. Blum, T. F. Abdelzaher, J. A. Stankovic, and T. He. “RAP: A real-time communication architecture for large-scale wireless sensor networks,” in 8th IEEE Real-Time and Embedded Technology and Applications Symposium, 2002, pp. 55- 66.

[8] Ian F. Akyildiz, Ismail H. Kasimoglu, “Wireless sensor and actor networks: research challenges,” *Ad Hoc Networks*, vol. 2 no. 4, Oct. 2004, pp. 351–367.

[9] Suman Saha, Mitsuji Matsumoto, “A framework for data collection and wireless sensor network protocol for disaster management,” IEEE COMSWARE 2007, 7-12 Jan. 2007.

[10] W. Heinzelman and A. Chandrakasan and H. Balakrishnan, “Energy-application-specific protocol architecture for wireless microsensors”, *IEEE Trans. on Wireless Communications*, vol. 1, no. 4, Oct. 2002, pp. 660-670.

[11] S. Selvakennedy and S. Sinnappan, “An adaptive data dissemination strategy for wireless sensor networks,” *International Journal of Distributed Sensor Networks*, vol. 3, Issue 1, Jan. 2007, pp. 23-40.

[12] Z. Chaczko, R. Klempous, J. Nikodem, M. Nikodem, “Methods of sensors localization in wireless sensor networks,” Proc. of the 14th Annual IEEE Int. Conf. and Workshops on the Engineering of Computer-Based Systems (ECBS'07), 2007, pp. 145-152.

[13] T. Y. Chen, C. C. Chiu, T. C. Tu, “Mixing and combining with AOA and TOA for the enhanced accuracy of mobile location,” in Proc. of 5th European Personal Mobile Communications Conf., Apr. 2003, pp. 276-280.

[14] P. Deng, P. Z. Fan, “An efficient position-based dynamic location algorithm”, in Proc. of International Workshop on Autonomous Decentralized Systems, 2000, pp. 36-39.

[15] N. Patawari, A. O. Hero III, “Location estimation accuracy in wireless sensor networks”, 36th Asilomar Conf. on Signals, Systems and Computers, 2002, vol.2, Nov. 2002, pp. 1523-1527.

[16] A. Tarighat, N. Khajehnouri, A. H. Sayed, “Improved wireless location accuracy using antenna arrays and interference cancellation”, Proc. of IEEE Int. Conf. on Acoustics, Speech, and Signal Processing, 2003 (ICASSP '03), vol. 4, Apr. 2003, pp. 616-619.

[17] L. Cong, W. Zhuang, “Hybrid TDOA/AOA mobile user location for wideband CDMA cellular systems”, *IEEE Trans. on Wireless Communications*, vol.1, No.3, July 2002.

[18] F. Gustafsson, F. Gunnarsson, “Positioning using time-difference of arrival measurements”, Proc. of IEEE Int. Conf. on Acoustics, Speech, and Signal Processing, 2003 (ICASSP '03), vol. 6, Apr. 2003, pp. 553-556,.

[19] A. Ault, X. Zhong, and E. J. Coyle, “K-nearest-neighbor analysis of received signal strength distance estimation across environments”, First Workshop on Wireless Network Measurements (WiNMee 2005),Trentino, Italy, Apr. 2005.

[20] G. Ranjan, A. Kumar, G. Rammurthy, and M. B. Srinivas, “A natural disasters management system based on location aware distributed sensor networks,” IEEE Int. Conf. on Mobile Adhoc and Sensor Systems Conf., Nov. 2005, pp. 180- 182.

[21] D. Ganesan, D. Estrin, and J. Heidemann, “DIMENSIONS: Why do we need a new data handling architecture for sensor networks?,” Proc. of the ACM HotNets, Princeton, NJ, USA, October 2002, pp. 143-148.

[22] J. Heidemann, F. Silva, C. Intanagonwiwat, R. Govindan, D. Estrin, and D. Ganesan, “Building efficient wireless sensor networks with low-level naming.” Proc. of the 18th ACM Symposium on Operating Systems Principles, Banff, Alberta, Canada, 2001, pp. 146-159.

[23] C. Intanagonwiwat, R. Govindan, D. Estrin, J. Heidemann, and F. Silva, "Directed diffusion for wireless sensor networking," *IEEE/ACM Trans. on Networking*, vol. 11 , no. 1, Feb. 2003, pp. 2-16.

[24] S. Shenker, S. Ratnasamy, B. Karp, R. Govindan, and D. Estrin, "Data-Centric storage in sensornets," *ACM Computer Communication Review*, vol. 33 , Issue 1, 2003, pp. 137-142.

[25] S. Kim, S. H. Son, J. A. Stankovic, and Y. Choi, "Data dissemination over wireless sensor networks," *IEEE Communication Letters*, vol. 8, no. 9, Sep. 2004, pp. 561-563.

[26] G. Amato, P. Baronti, S. Chessa, "MaD-WiSe: programming and accessing data in a wireless sensor network," Int. Conf. on Computer as a Tool (EUROCON 2005), Nov. 2005, pp. 1846-1849.

[27] W. Heinzelman and A. Chandrakasan and H. Balakrishnan, "Energy-Efficient communication protocol for wireless microsensor networks." In Proc. of the 33rd annual Hawaii Int. Conf. on System Sciences, vol. 2, Jan. 2000.