Comparison of Routing Protocols for Locating moving object in Large Scale Cellular Wireless Sensor Network

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Abstract

A Wireless Sensor Network (WSN) is ad hoc dense wireless network of small, low-cost sensor nodes (SN), which collect and disseminate sensed data with limited power sources. WSNs can be used in many applications, such as environmental monitoring and object tracking. Organizing network topology with energy efficient traffic can maximize network lifetime.

A cellular architecture based on organizing SNs according to their geographical position had been introduced. It uses inheritance features to organize and reduce traffic. It works with ALL-Active (AA) SNs. Moreover, two Energy aware models are suggested to prolong the WSN lifetime. The first uses Cellular Automata (CA) rules and the second uses Radio Triggered (RT) SNs.

Multi-hop, Static Tree, Aggregated Tree, Static cluster, and dynamic cluster based routing protocols has been designed and compared for AA, CA, and RT architectures resulting in longest network lifetime with no overhead communication for RT network with least energy consumption applying dynamic cluster routing.

Keywords- *Wireless Sensor Network, Cellular network, Ad-Hoc.*

1. Introduction

The development of large-scale sensor networks has drawn a lot of attention. Therefore, the large size of wireless sensor networks inevitably introduces significant scalability concerns. One of the main challenges is then to set up new architectures and mechanisms that can efficiently scale up with the growing number of nodes [1][2][3].

Large-scale WSNs consist of hundreds and thousands of nodes, and each node is able to sense the environment, perform simple computations and communicate with its other sensors or to the Based station, which is a central unit. The sensor node has qualities of low-cost, small size and power-saving. However, these qualities put bonds to the energy, storage capacity and computing ability. The most influential factor is the restriction to energy [4]. Achieving maximum lifetime in WSNs by optimally using the energy within sensor nodes has been the subject of significant researches in the last recent years. In this field, radio transmission and reception operations are being identified as one of the most energy consuming features.

Recently WSNs are often used to replace mankind with sensor nodes to obtain the information which is unable for human beings. Hence its applications is widespread, such fields in environmental, health, military. The military community is interested in deploying WSN to provide battlefield surveillance, reconnaissance, and battle damage assessment [5]. In these applications, WSN are deployed on-demand to monitor large terrains and obtain timely information about the enemy activities. Therefore, there is a need for a specially designed large scale WSN for object tracking.

The research here introduced large scale WSN specially designed for object tracking using acoustic sensors. Two energy aware architectures are also designed to prolong network lifetime. A design for Multi-hop, Static Tree, Aggregated Tree, Static cluster, and dynamic cluster based routing protocols is introduced and compared for the three network models.

The rest of the paper is organized as follows: section 2 is the previous work, section 3 contains the proposed cellular network architecture, section 4 includes two energy aware architectures, section 5 apply location of moving object to the suggested architectures with designs for the previously mentioned routing protocols, section 6 contains the simulator and its results and a comparison between the routing protocols through the networks, and section 7 concludes the paper.

2. Previous work

Moving object tracking using WSN has received considerable attention in recent years and intended solutions can be mainly classified into four schemes, which are: tree - based tracking, cluster-based tracking; prediction-based tracking; mobicast message-based tracking methods[7].

In tree-based target tracking, nodes in a network may be organized in a hierarchical tree or represented as a graph in which vertices represent SNs and edges are links between nodes that can directly communicate with each other.

In the cluster architectures, clusters are formed statistically at the time of network deployment and the properties of each cluster are fixed such as number of members, area covered. Static clustering is simple but has scalability problems. In contrast, dynamic clustering offers several advantages where clusters are formed dynamically depending on occurrence of certain events, thus redundancy data and interference is reduced [8].

Prediction-based tracking processes historical data depending on the object moving pattern to deduce subsequent movement of a mobile object [9].

Mobicast message-based tracking depends on prediction. It is a spatiotemporal multicast method in which message is delivered to a group of nodes that change with time according to estimated velocity of moving entity [10].Some protocols employ clustering, prediction and scheduling mechanism thus giving better performance in terms of energy consumption as compared to other approaches but further metrics still need to be investigated [11].

3. Proposed Cellular Architecture:

Topology Control Problem: Topology Control Problem in WSN can be divided into two categories: Sensor Coverage Topology and Sensor Connectivity Topology. The coverage topology describes the topology of sensor coverage and is concerned about how to maximize a reliable sensing area while consuming less power. The connectivity topology on the other hand is more concern about network connectivity and emphasizes the message retrieve and delivery.

Sensor Energy Consumption: The energy consumed by the transmitting circuit is related with the distance transmitted the message [18]. The energy consumed by sending m bits message is calculated as follow:

$$E_{trans}(m,d) = \begin{cases} E_{elec} * m + E_{fs} * m * d^2 & \text{if } d < d_0 \\ E_{elec} * m + E_{mp} * m * d^4 & \text{if } d \geq d_0 \end{cases} \quad (1)$$

and to receive this message, the radio expends:

$$E_{rec}(m) = E_{elec} * m \qquad (2)$$

$E_{trans}(m，d)$is the energy consumed by sending m bites of messages. $E_{rec}(m)$ is the energy consumed by receiving m bites of messages. d is the transmission distance. E_{elec} is the energy consumed by receiving or sending one bites of message. E_{fs} is the transmission constant of freedom space. E_{mp} is the comedown transmission constant of multi-path. E_{fs} and E_{mp} is related with the model of transmission channel used in the wireless sensor network. d_0 is the maximum of transmission distance.

$$do = \sqrt{\frac{E_{fs}}{E_{mp}}}$$

- ***Network initialization and localization:***

Deterministic deployment of large WSNs is impractical due density required to provide appropriate network coverage. Furthermore, several applications of WSN are expected to operate in hostile environments [12]. Consequently, stochastic deployments become more feasible [13]. Stochastic deployment makes the network topology random. Since there is no a priori communication protocol, the network is ad hoc. According to the hostile environment in which the WSN can be deployed, increasing the number of sensors, to correlate the detection signals and so to maximize the probability of an accurate detection can be a solution. For these circumstances precise knowledge of node location in ad hoc sensor networks is an essential step in wireless networking. Unfortunately, for a large number of SNs, straightforward solution of adding GPS to all nodes in the network is not feasible due to the high cost of GPS.

Consider the case when we have deployed a sensor network consist of n sensors, with some SNs equipped with GPS are installed in the field known as *anchors* or *beacons*. Initially, anchors are aware of their own positions. Then all the other nodes localize themselves with the help of location references received from the anchors using the hyperbolic trilateration method introduced in [14]. This process ends with the result that all the SNs in the network knows its own position N(x,y).

Cellular layer deployment: Communication cost in WSNs is at least two orders of magnitude higher than computation costs in terms of consumed power [15]. This communication-computation trade-off is the core idea behind low energy sensor networks. The suggested architecture applies a virtual cellular layer deployment over the unstructured network area as shown in Fig. 1 to organize and reduce communication through the network.

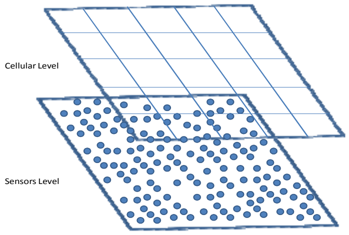

Fig. 1 Cellular-layer deployment

The network suggested architecture is as follows:

- **Wireless sensor network environment:**
  - Assuming an area that we will deploy sensor nodes in as a coordinate known area and we will denote it as network area.

- The system has a single base station (BS) located at the center of that network area in order to be closer to all sensors in the network.
- Sensors deployed in the network area are assumed to be uniformly and densely distributed over the network area and initially have equal battery powers.
- As shown previously in the equation above, when transmitting a packet distance less than do, the sending energy consumed proportional to square the transmitted distance. Also the equation shows that, when transmitting a packet distance exceeds do, the sending energy consumed proportional to quadratic the transmitted distance. Therefore, in order not to increase the energy consumption of sending packets, we say that the ***communication range*** is the circle surrounding the sensor node that its center is the sensor node and its radius is R_{com} equals to do.
- The sensor node's ***sensing range*** is assumed to be as circle its center is the sensor node and its radius is R_{sense}
- The sensing range of a sensor node is assumed to be half its communication range. Therefore $R_{com} = 2 R_{sense}$.
- *Cells Definition*: The network area is divided into equal sized non-overlapping areas called cells. Each cell has a known coordinates, and its size is assumed to be less than the sensing range of the deployed sensors as shown in figure 3. All sensor nodes belonging to one cell are assumed to have a common sensing and communication ranges. The communication range of a cell can be defined as the intersection of the communication ranges of the four sensor nodes residing at the corners of the cell. Also the sensing range can be defined as the intersection of the sensing ranges of the four sensor nodes residing at the corners of the cell. Both ranges are shown in figure 3. Applying the localization algorithm, described in the previous section, each node will identify its coordinates, consequently identifying to which cell it belongs.

*Cell Identification***:** Each cell is identified by a pair of numbers (x,y), as shown in figure 2 starting from the origin , cell(0,0) in which the based station is located, and outwards to include all the network area.

The cell size: The maximum cell diagonal can be identified as $d_0/4$, as shown in figure 4. Therefore each cell can be projected to network area as a $S_{cell} * S_{cell}$ square, where

The cell Diagonal is $d_0/4 = \sqrt{2}(S_{cell})^2$

Thus the cell side can be calculated as

$$S_{cell} = \frac{d_0}{4\sqrt{2}}$$

$$S_{cell} = \frac{\sqrt{E_{fs}}}{4\sqrt{2 * E_{mp}}}$$

(-5,5)	(-4,5)	(-3,5)	(-2,5)	(-1,5)	(0,5)	(1,5)	(2,5)	(3,5)	(4,5)	(5,5)
(-5,4)	(-4,4)	(-3,4)	(-2,4)	(-1,4)	(0,4)	(1,4)	(2,4)	(3,4)	(4,4)	(5,4)
(-5,3)	(-4,3)	(-3,3)	(-2,3)	(-1,3)	(0,3)	(1,3)	(2,3)	(3,3)	(4,3)	(5,3)
(-5,2)	(-4,2)	(-3,2)	(-2,2)	(-1,2)	(0,2)	(1,2)	(2,2)	(3,2)	(4,2)	(5,2)
(-5,1)	(-4,1)	(-3,1)	(-2,1)	(-1,1)	(0,1)	(1,1)	(2,1)	(3,1)	(4,1)	(5,1)
(-5,0)	(-4,0)	(-3,0)	(-2,0)	(-1,0)	● BS (0,0)	(1,0)	(2,0)	(3,0)	(4,0)	(5,0)
(-5,-1)	(-4,-1)	(-3,-1)	(-2,-1)	(-1,-1)	(0,-1)	(1,-1)	(2,-1)	(3,-1)	(4,-1)	(5,-1)
(-5,-2)	(-4,-2)	(-3,-2)	(-2,-2)	(-1,-2)	(0,-2)	(1,-2)	(2,-2)	(3,-2)	(4,-2)	(5,-2)
(-5,-3)	(-4,-3)	(-3,-3)	(-2,-3)	(-1,-3)	(0,-3)	(1,-3)	(2,-3)	(3,-3)	(4,-3)	(5,-3)
(-5,-4)	(-4,-4)	(-3,-4)	(-2,-4)	(-1,-4)	(0,-4)	(1,-4)	(2,-4)	(3,-4)	(4,-4)	(5,-4)
(-5,-5)	(-4,-5)	(-3,-5)	(-2,-5)	(-1,-5)	(0,-5)	(1,-5)	(2,-5)	(3,-5)	(4,-5)	(5,-5)

Fig. 2 cell identification

- **Communication range versus Communication cells:** By projecting the communication range to the cellular layer, hence considering the cells belonging to the communication range forming a square around certain cell as the ***communication cells*** of sensors belonging to that cell, as shown in figure 3.
- **Sensing range versus Sensing cells:** by projecting the sensing range of sensors belonging to a certain cell to the cellular layer the same way we did in the communication range, we can say that the ***sensing cells*** are the cells forming a square around that cell and belonging to the ***sensing range*** of the cell's sensors, as shown in figure 3.

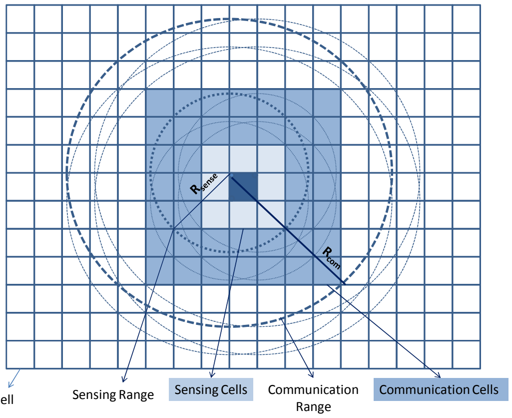

Figure 3 Communication cells and sensing cells

- **Processing Node:** In order to minimize the number of redundant packets transmitted to the base station, a processing node concept is introduced. The processing node of the cell is responsible for receiving all the packets sent to that cell and fuses these packets as a one aggregated packet to the next target cell. The processing node is elected for each cell as follows: The first sensor node locates itself in the cell claims itself as the processing node of that cell. The processing node dissipates its energy faster than other nodes in the cell due to the aggregation and routing responsibilities assigned to it. When the processing node reaches a certain energy threshold E_{th} at the time instant T, it broadcasts a "request for a new processing node" message "Req-new-PN" to all nodes in the cell. E_{th} can be calculated as

$$E_{th} = E_{trans} + E_{active}$$

Where E_{trans} is the energy consumption of transmitting one message within the cell And E_{active} is the energy needed to keep a sensor active for one second.

Each node receives the "Req-new-PN" message broadcasts a message to all nodes in the cell to announce itself as the new processing node to that cell at time $T_{announce.}$. $T_{announce}$ is calculated as

$$T_{announce} = T + T_r$$

Where T_r is a random number between 0 and 1.

This guarantees that the new processing node will be announced in a time interval less than or equal to one second, hence before the old processing node dissipates all of its energy and dies. If the node receives one new processing node announcement before its $T_{announce}$, it aborts the process of claiming itself as the new processing node of the cell. A node detects a collision in two of the following cases: first if it receives two or more processing node announcements, in that case it will proceeds in the process of claiming itself as the new processing node normally. The second case is when it sends an announcement itself and receives other announcements. In that case it will calculate a new $T_{announce}$ and repeat the process of announcing itself as the new processing node all over again.

- *Communication Model:* Packets sent through the network can be categorized as "*data packets",*" *Setup Packets",* and " *information packets*". Data packets contain sensed data of a SN. SNs share data packets to form information packets. Setup packets are the packets that used within the cell of PN election. Information packets contain the location of the moving object and need to be fused to the Base station. Each packet, either data, setup or information packet, have a header contains the target cell id and the packet type. The target cell id is Null in the *data packet*, and is the same cell id as the sender's cell id in the setup packet. *Sending Process:* A SN sends a packet by broadcasting it thought the SN's communication range. *Receiving Process:* a SN receives a packet checks the target cell in the packet header. If the target cell is Null then the packet is a data packet and the SN stores the content of this packet to use it later in forming an information packet. On the other hand, if a SN receives a packet with a non-Null target cell value, then SN checks the packet type, if it is a setup packet and belongs to the same cell as the receiver SN, it deals with it in the previously illustrated PN election process. The SN receives and fuses the information packet only if the SN is a PN and residing in the target cell, otherwise it just discards the information packet.

The benefits of applying cellular layer to the network area are:

- Cellular layer guarantees certain level of organization through the ad-hoc network structure.
- The routing between nodes in cellular arrangement is simple. The routing operations are applied to the cellular layer rather than nodes' layer. The node sends a packet through the route by fusing the packet to the next cell in the route through the network without necessity knowledge of the exact location of the next node in the route.
- The cellular architecture makes use of the inheritance property. In cellular architecture ***scalability*** of nodes is guaranteed as any node can be deployed to the network and locates itself to a certain cell, hence automatically inherits the cell properties in which it belongs, ex. The next routing cell, its parent cell if it is in a tree-based structure or its cluster head cell if it is in a cluster based structure, therefore operates within the network without an extra deployment costs.
- ***Fault tolerance*** of nodes is guaranteed. Node failures do not affect network operations, since sensing and routing operations are implemented in the term of cells rather than nodes.

4. Energy aware Cellular architectures:

The results showed that activating all the sensor nodes shorting the total network lifetime. Running an energy aware architecture prolongs the network lifetime compared to the worst case where all sensor nodes happen to be active. Therefore, the cellular architecture can make use of the *sensors' modes*. The sensors have different modes each consuming different amount of its battery power; these modes are defined in table 1.

Table1. Sensor node modes

Sensor node mode	Description
Stand-by	Sensing and communication components of the node are switched off and only the computation component is switched on.
Active	All sensor node three components, sensing , computation and communication, are switched on
Sleep	All sensor node three components, sensing , computation and communication are switched off

Energy aware cellular architecture is implemented by trying to put group of sensors in a standby mode in order to save their battery power thus maximizing the whole network life time and also reduce the information redundancy routed through the network. To guarantee uninterrupted routing, the processing node in each cell has to be in the active mode all the cell life time. The suggested Energy aware architectures are the Cellular Automate based architecture CA and the Radio Triggered based architecture RT.

4.1. Cellular Automata Based Architecture:

Many areas of research have been benefited with the theories related to the cellular automata, mainly the areas that need to deal with systems that are constantly changing or have a random behavior as Wireless sensor networks. In [16][17], the authors introduced and used the cellular automata to simulate the large wireless sensor networks architecture. The suggested energy aware cellular automata based architecture applies the following rules:(1) A sensor that is in a standby mode on time *t* comes back to active mode on time $t + 1$ if less than two sensors in the same cell that it belongs to are in active mode. (2) A sensor that is in active mode on time *t* go to standby modes on time $t + 1$ if, on time *t*, two or more sensors in the same cell that it belongs to are in active mode.

The suggested cellular automata based architecture works as follows: In the beginning of simulation, all the sensor nodes deployed, are assumed to work in an active mode. The first sensor node in a cell locates itself is assumed to be the processing node PN of that cell. The PN of a cell does not perform the cellular automata rules and always works in an active mode. For each active sensor, not PN, after a random time T_r the active sensor reaches a checking point. In the checking point, the sensor node decides whether it stays in the active mode or goes to a standby mode by applying the previously declared cellular automata rules. Also the sensor node running in a standby mode goes to an active mode after a random time T_r and applies the cellular automata rules in order to decide the mode it will run under. In any checking point for any node in a cell, if the sensor finds zero active sensors, it assumes itself as the PN of that cell. After the entire energy of a sensor is consumed, the sensor goes to the sleep mode and becomes inactive; this process continues until all the sensor nodes' energy is consumed (i.e. all the cells are inactive). The responsibility of the PN in any cell is delegated through the active sensors at the time instance at which the PN sensor battery reaches the E_{th}, as described earlier. Cellular automata rules application packets sent through the cell are assumed to be setup packets.

4.2. Radio Triggered Based Architecture:

In [18] radio-triggered power management, a special hardware component – a radio-triggered circuit – is connected to one of the interrupt inputs of the processor. The circuit itself does not have any power supply. The node can enter a standby mode without periodic wake-up. When a power management message is sent by another node within a certain distance, the radio-triggered circuit collects enough energy to trigger the interrupt to wake up the network node. This is significantly different than using the radio transceiver to listen to messages because a listening radio transceiver requires help from the processor (or a radio sub-controller) to conduct channel monitoring and message parsing and the listening process consumes energy of the node. The radio-triggered circuit, on the contrary, is powered by the radio signals themselves. It is powered off when there are no suitable radio signals and naturally starts working when suitable radio signals arrive. Except for activating the wake-up interrupt, the radio-triggered circuit is independent of any other components on the node.

The suggested cellular radio triggered architecture works as follows: The first sensor locates itself in a cell is assumed to be the Processing node PN of that cell and works in an active mode. For any successive sensors locating themselves in that cell, they work in a standby mode. If the energy level of the current processing node reaches a certain threshold at time T, which means that this sensor node is running out of energy. Thus it sends a radio signal to the nodes in its cell to pick up the new PN. Each sensor node receives a radio signal waits a random time T_r between 0 and 1, and then goes to an active mode setting itself as the PN of that cell. If a standby sensor node received a radio signal at time T and picks up its random time T_r, then received another radio signal at time less than $T+T_r$ then it aborts the operation of waking itself up to an active mode. This procedure guarantees that at any time instance only one sensor in a cell is in the active mode working as the processing node of that cell and all the other sensors in that cell are in a standby mode.

5. Locating moving object in the cellular architecture:

5.1. Sensing an object:

In [19] a survey of current available positioning techniques, their comparison, and subsequent recommendation of which technique is appropriate for use depending on specific application is presented. Using acoustic sensors, the trilateration method is the most appropriate method to use to locate an object. Whenever an object is moving in the network, it will be detected by a group of sensor nodes in its sensing range. At a *t* time instant, all the sensors that in the object's sensing range have to locate the object. Each sensor senses the object needs its measurement and two other measurements from other sensors to locate the object.

To apply the trilateration method to the suggested cellular architecture, active sensor nodes in the sensing cells of the object and not processing nodes sends a packet of its measurement locally inside the cell in which that sensor belongs and receive two other measurements to identify the objects position. If the sensor sensing an object is a Processing node sensor, then it broadcasts a packet of its measurement to a distance equals to two cells ahead. These Processing nodes broadcasts are made to two-cells ahead distance in order to ensure that in case all sensor nodes died in all sensing cells except for processing nodes, each processing node in a sensing cell will receive packets from other sensing cells and hence can locate the object. Then the object location is identified by its coordinates (X_{obj},Y_{obj}).

Using the object's coordinates (X_{obj},Y_{obj}) , the cell in which the object resides can be identified and known as the ***residential cell***. Only the sensor nodes belonging to the residential cell sensing cells are allowed to create information packets recording the object movement. Each information packet containing the location of the sensed object and the time instant at which the object is sensed at this specific location.

5.2. Routing packets to the base station:

After the information packets are created, the sensor nodes fuse them to the base station. The fusions are performed by the following scenarios:

1. Direct transmission:

The radio transmission energy dissipation includes two parts of radio electronics energy and power amplifier energy. Generally the amplifier energy required for a successful transmission is much larger than the radio electronics energy and dominates the transmission energy dissipation.

- **Sending packets Energy consumption simulation:**
- To send a packet through the network, the energy consumption of the sending process depends on the distance between the sending and the receiving sensor nodes. Assume that the sending distance is defined as d, d can be simulated as follows:
- If the packet is sent locally between two sensors inside one cell, then the maximum distance travelled by this packet will be

$$d = \text{Cell Diagonal} = d_0 /4 = \sqrt{\frac{E_{fs}}{E_{mp}}}/4$$

- If the packet is sent between two nodes in two different cells, defined as sending cell S and receiving cell R, then the maximum sending distance d between these two sensors can be calculated as:

$$d = (\text{CellDist(S,R)} + 1) * \text{Cell Diagonal}$$

- Where CellDist(S,R) is the number of cells between the sending cell S and the receiving cell R. CellDist(S,R) can be easily calculated assuming the sending cell is cell S(X_s, Y_s) and the receiving cell is R(X_r, Y_r)

$$\text{CellDist(S,R)} = \text{Maximum}\ (|X_s - X_r| , |Y_s - Y_r|)$$

- Deploying the distance estimation in the sending energy consumption equations allowing estimate for the sending process. The estimation is as follows: assume that sensor A residing in cell *S* is sending an *m*-bit packet to sensor B residing in cell *R*, and the CellDist(S,R)=CellDist , then the sending energy consumption can be calculated as:

$$E_{trans}(m, CellDist) = \begin{cases} m * (E_{elec} + \frac{E_{fs}^2 * (\text{CellDist}+1)^2}{16 * E_{mp}})\ where\ CellDist \le 3 \\ m * \left(E_{elec} + \frac{E_{fs}^2 * (\text{CellDist}+1)^4}{256 * E_{mp}}\right) where\ CellDist > 3 \end{cases}$$

2. Multi-hop fusion:

According to the free space channel model, as described earlier, the minimum required amplifier energy is proportional to the square of the distance from the transmitter to the destined receiver (E_{trans} α d^2) [19]. So the transmission energy consumption will increase greatly as the transmission distance rises. It means that sending packets directly from the sensor nodes to the base station consumes much energy than a multi-hop transmission. Therefore a multi-hop transmission routing is preferably applied in the cellular based architecture of our WSN. The multi-hop fusion will be applied as follows:

1. Each sensor senses a moving object and belongs to its sensing cells, creates a data packet to route.
2. If the sensor is not the processing node in the cell, the sensor sends its data packet to the processing node of the cell in which it belongs.
3. If the sensor is the processing node in the cell, it aggregates all the data packets sent to it by the sensors in the cell and creates one aggregated data packet to route.
4. The processing node determines the next ***target cell*** to which it will send its packet.
5. The ***target cell*** has to be at most three cells ahead towards the base station, which will be the farthest cell that can be reached in the communication cells of the cell in which the processing node belongs. The target cell can easily be identified by the numbering system defined above.
6. The processing node sends its aggregated packet to the processing node in the target

cell. The process are re implemented at the target cell to the next target cell until the packet reach the origin cell (0,0) in which the based station is located.

3. Static Tree-Based Routing :

The tree based routing depends on building a geographically designed tree to transmit data packets through it until it reaches the base station. The tree configuration is based upon the geographical location of the network's cells. Tree routing can reduce the data redundancy packets that can be transmitted to the base station where each parent cell will aggregate data packets created by its leaf cells.

- **Tree formulation**

1. Set the root cell for the tree as cell (0, 0).
2. All the cells belonging to the communication cells of the root cell are set as children cells for the root (0, 0). And these cells are considered as level 1 of the tree.
3. Determining the cells belonging to the next level in the tree. Those cells are in communication cells for the outer frame of current cell.
4. Each level corner cells are easily identified as the parent of the tree's next level.
5. Other cells belonging to outer frame of the next level are added to the parent cells in which distance between two parents should be at most 6 cells.
6. For each cell in the next level, assigning a parent cell that belonging to its communication cells and has no previously assigned parent.
7. Repeating steps 3:6 until all cells in the network area join the tree.

Therefore, all sensors belonging to a certain cell inherit their cell properties, either it is a parent cell and/or it is a child cell to a predefined parent. Insertion of new sensors in the network area needs no tree reformulation. The routing process in the tree based cellular architecture presented is implemented as follows:

1. The nodes that sense the moving object determine its residential cell.
2. Only the nodes belonging to the sensing cells of the residential cell of an object create data packets.
3. The data packets created are sent from the sensor node, which is not processing node, to the processing node of the cell in which it belongs.
4. The processing node aggregates the packets sent to it from the sensing sensors in the cell in which it belongs to one packet.
5. The processing node sends the aggregated packet to its assigned parent cell's processing node.
6. The processing node in the parent cell will aggregate data packets from its children cells and then fuses the aggregated packet to its own parent.
7. This procedure is repeated until the data packets delivered to the base station.

4. Aggregation-tree-Based Routing:

The geographical-tree based routing consumed more energy at parent cells, as parent cells are fixed cells in the network. This over-energy consumption at the parent cells causes them to die before the non-parent cells. Therefore, all the children of that died parent cell cannot transmit packets to the base station and hence leads to failure in that part of the network. In order to overcome this problem a dynamic aggregation tree for each sensed object is formulated. Therefore, at a time instant t, and target is moving through the network:

1. The nodes that sense the moving object determine its residential cell.
2. Only the nodes belonging to the sensing cells of the residential cell of an object create data packets.
3. The data packets created are sent from the sensor node, which is not processing node to the processing node of the cell in which it belongs.
4. The processing node aggregates the packets sent to it from the sensing sensors in the cell in which it belongs to one packet.
5. The Processing node defines the farthest cell in its communication cells towards the base station for the cell in which it belongs is its parent cell.
6. The aggregated packet is sent to the parent cell's processing node.
7. The processing node in the parent cell will aggregate data packets from all its children cells and then fuses the aggregated packet to its own parent, which is determined the same way in step 5.
8. This procedure is repeated until the data packets delivered to the base station.

5. Static-Cluster Based Routing:

In the conventional cluster architecture, clusters are formed statistically at the time of network deployment and the properties of each cluster are fixed such as number of members, area covered, etc. Static clustering has several drawbacks regardless of its simplicity, for example, static membership is not robust from fault-tolerance point of view and it prevents importing new sensor nodes in the network.

In the proposed architecture a geographically static clusters are formed through the network with a static cell acting as a cluster head cell. In the cluster head cell each senor node takes the responsibility as a cluster head node for the cluster successively. Simply the PN of the cluster head cell takes the responsibility as cluster head sensor.

The cluster is formed by the all the cells belonging to the communication cells of the cluster head cell. Consequently all the sensors belonging to those cells forming the cluster are considered as cluster member nodes. The cluster head cell is assumed to be located at the origin of the cluster and is reachable to all sensors belonging to the cluster by one message only. As declared previously, the maximum communication range that gives reasonable energy consumption in sending packets is three cells. So the clusters are assumed to be of size 7*7 cells, having the cluster head node at the origin of the cluster.

The proposed clustering technique combines the simplicity of the static clustering, as no need for cluster periodic reformation. It also can have the properties of dynamic clustering as it can handle nodes scalability of the network. If a new sensor node imported in the network, it automatically locates itself and determines its cell, consequently determining to which cluster it belongs without a need for a joining messages between the imported node and the cluster head node. The cluster routing is implemented as follows:

1. The nodes that sense the moving object determine its residential cell.
2. Only the nodes belonging to the sensing cells of the residential cell of an object create data packets.
3. The data packets created are sent from the sensor node, which is not processing node to the processing node of the cell in which it belongs.
4. The processing node aggregates the packets sent to it from the sensing sensors in the cell in which it belongs to one packet.
5. The processing node sends the aggregated packet to the cluster head node in the cluster head cell for the cluster in which it belongs.
6. The cluster head node aggregates all data packets from its member cells and then fuses the aggregated packet to the base station in a multi-hop transmission fashion through the elected processing nodes in the route cells, as described earlier.
6. <u>Dynamic Cluster Routing:</u>

In contrast, dynamic clustering offers several advantages where clusters are formed dynamically depending on occurrence of certain events. For the suggested dynamic cluster based routing, the cluster is formed through the tracking process based on the geographic position of the object being tracked. Since sensors don’t statistically form a cluster, they may belong to different clusters at different timings. As only one cluster is active at a time, redundant data and interference is reduced.

Forming the cluster in the dynamic clustering is as follows: The residential cell of an object is assumed to be the current cluster head cell. The processing node in the current cluster head cell will be the current cluster head node. The cluster member cells will be the cells in the sensing cells of the residential cell, which are one cell ahead surrounding the cluster head cell. Consequently, all the nodes belonging to the cluster member cells are assumed as member nodes of the current cluster.

The object tracking process will be performed as follows:

1. The nodes that sense the moving object determine its residential cell.
2. Only the nodes belonging to the sensing cells of the residential cell of an object create data packets.
3. The data packets created are sent from the sensor nodes, which is not processing node to the processing node of the cell in which they belong.
4. The processing node aggregates the packets sent to it from the sensing sensors in the cell in which it belongs to one packet.
5. The aggregated data packets created at the processing nodes in the member cells are sent to the cluster head node (which is the processing node of the residential cell).
6. The cluster head node aggregates data from all current cluster member cells and fuses the aggregated packet containing the object location and time instant using the previously described multi-hop aggregated routing protocol through the processing nodes of the route to the base station.

The advantage of using the dynamic cluster head routing through the cellular architecture is that, whenever an object moves the cluster is reformed by the cluster head cell, which will always be the residential cell of the object. Also the member cells of the cluster will always be the cells surrounding the cluster head cell. Therefore, the cluster head node will also be automatically recognized by all the cluster member nodes as the processing node of the cluster head cell. No extra messages need to be sent to determine the cluster size, member nodes, or the cluster head node for the current cluster. That means no overhead energy consumption is needed for forming the dynamic cluster while the object is moving.

6. Simulation model

The proposed architecture is implemented to simulate a large stochastic and densely deployed wireless sensor network. The implementation was constructed as follows:

- **Network modeling:** The coverage area consists of 33*33 squared cells each containing 9 sensor nodes, with a random waypoint moving object with constant velocity crossing one cell per second .
- **Energy Modeling:** WSN sensor energy at the beginning of operation = 2 J **.** The energy of an WSN sensor node in ***active mode*** decreases by 0.0165 J every time step (in our case every 1 sec). The energy of a WSN sensor node in ***stand-by mode*** decreases by 0.00006 J every time step (in our case every 1 sec). Other parameters $E_{fs} = 10$ pJ/bit/m^2, $E_{mp} = 0.0013$ pJ/bit/m^4, E_{elec}= 50nJ / bit, m = 512 byte.
- **Performance measurements:**
- Global energy of the network: the sum of the residual energy remaining on all nodes in a specific point in time.
- Network lifetime: the time elapsed from the start of the simulation until all nodes run out of energy.
- Sensing energy consumption
- Overhead communication energy consumption which is caused by transmitting all the non information packets, and this takes place in the process of PN election and cellular Automata rules application.
- Routing-Protocols energy consumption comparison.
- Redundancy reduction which is the sensing to receiving packets ratio.

- **Simulation results***:*

Each point on the curve is the average of 20 runs with 90% confidence interval.

Figure 4 shows the reduction in energy consumption caused by using the multi-hop routing instead of direct transmission of packets sensing a moving object in an AA network. The multi-hop routing only uses maximum of 1.5% of the energy used when transmitting packets directly to the base station.

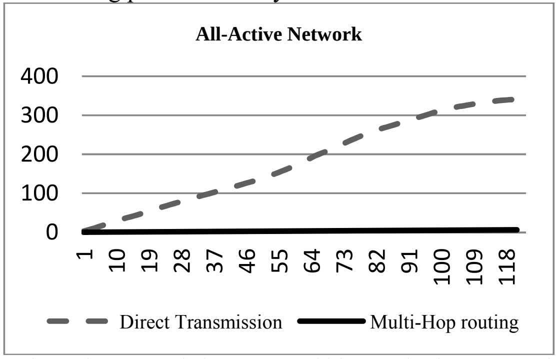

Fig. 4 Direct transmission versus multi-hop routing in AA network

Figure 5 shows a comparison of the various types of routing protocols used to transmit packets recording a moving object in an AA network. Results show that the aggregate tree routing protocol uses a minimum of 87.9% of the energy used by the multi-hop routing protocol. The static cluster routing protocol uses minimum of 74.5% of the energy used by the multi-hop routing protocol. The static tree based routing protocol uses a minimum of 71.6% of the energy used by the multi-hop routing protocol. Finally the best reduction given by the dynamic cluster based routing protocol, with minimum of only 67.7% of the energy used by the multi-hop routing protocol.

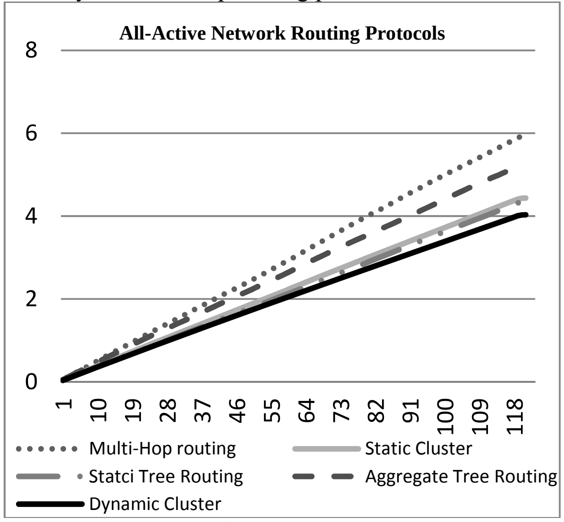

Fig 5 comparison of routing protocols over AA network

Figure 6 shows the number of delivered packets for all the routing protocols in the AA network. The results show that the redundancy reduction is a minimum in the dynamic cluster based routing, with only 6% of the sensed packets received at the base station. However only 7.4% of the sensed packets delivered to the base station with the tree based routing protocol, 10% with the static cluster based routing protocol, 30.7% with the aggregate tree routing protocol and 54.8% with the multi-hop routing protocol.

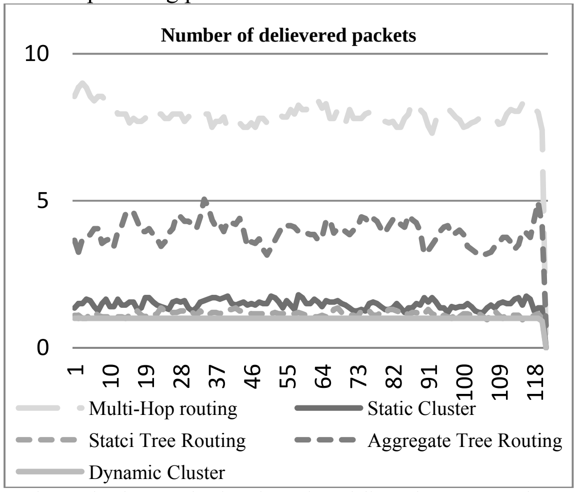

Fig 6 redundancy reductions in packets delivery in AA network

Figure 7 shows the reduction in energy consumption using the multi-hop routing instead of direct transmission of packets sensing a moving object in a CA network. The multi-hop routing only uses maximum of 2.2% of the energy used when transmitting packets directly to the base station.

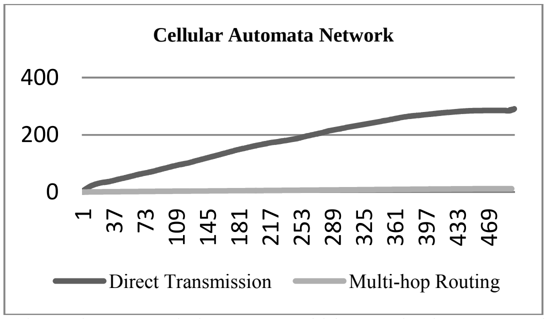

Fig. 7 Direct transmission versus multi-hop routing in CA network

Figure 8 shows a comparison of routing protocols used to transmit packets recording a moving object in a CA network. Results show that the aggregate tree routing protocol uses a minimum of 78.2% of the energy used by the multi-hop routing protocol. The static cluster routing protocol uses minimum of 48.3% of the energy used by the multi-hop routing protocol. The static tree based routing protocol uses a minimum of 46.3% of the energy used by the multi-hop routing protocol. Finally the best reduction given by the dynamic cluster based routing protocol, with minimum of only 38.1% of the energy used by the multi-hop routing protocol.

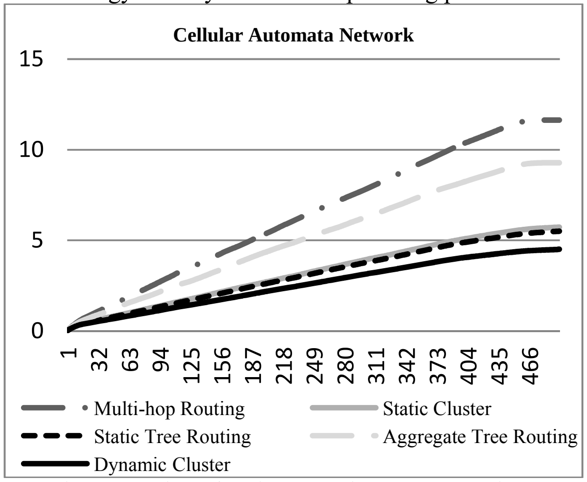

Fig. 8 comparison of routing protocols over CA network

Figure 9 shows the number of delivered packets ratio for all the routing protocols in the CA network. The results show that the redundancy reduction is maximized in the dynamic cluster based routing, then tree based routing protocol, Static cluster based routing protocol, aggregate tree routing protocol and finally the multi-hop routing protocol.

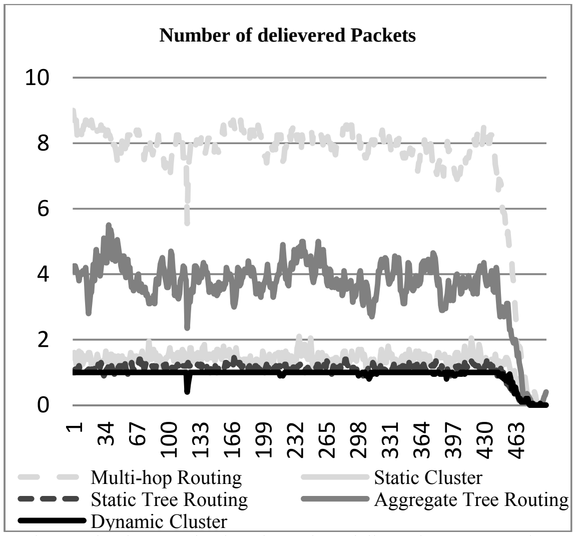

Fig. 9 redundancy reductions in packets delivery in CA network

Figure 10 shows the reduction in energy consumption using the multi-hop routing instead of direct transmission of packets sensing a moving object in a RT network. The multi-hop routing only uses maximum of 5.1% of the energy used when transmitting packets directly to the base station.

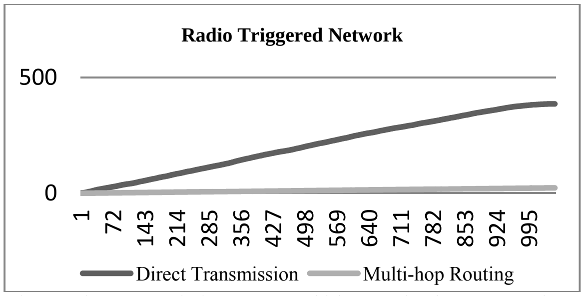

Fig. 10 Direct transmission versus multi-hop routing in RT network

Figure 11 shows a comparison of routing protocols used to transmit packets recording a moving object in a RT network. Results show that the aggregate tree routing protocol uses a minimum of 73.5% of the energy used by the multi-hop routing protocol. The static cluster routing protocol uses minimum of 39.2% of the energy used by the multi-hop routing protocol. The static tree based routing protocol uses a minimum of 37.1% of the energy used by the multi-hop routing protocol. Finally the best reduction given by the dynamic cluster based routing protocol, with minimum of only 28.1% of the energy used by the multi-hop routing protocol.

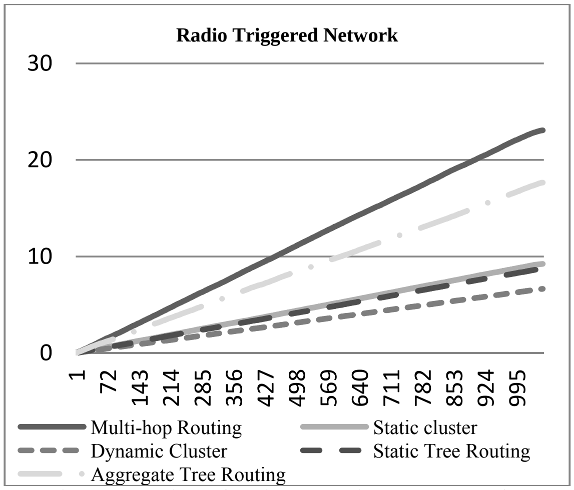

Fig. 11 comparison of routing protocols over RT network

Figure 12 shows the Sensed to delivered packets ratio for all the routing protocols in the RT network. The results show that the redundancy reduction is maximized in the dynamic cluster based routing, then tree based routing protocol, Static cluster based routing protocol, aggregate tree routing protocol and finally the multi-hop routing protocol.

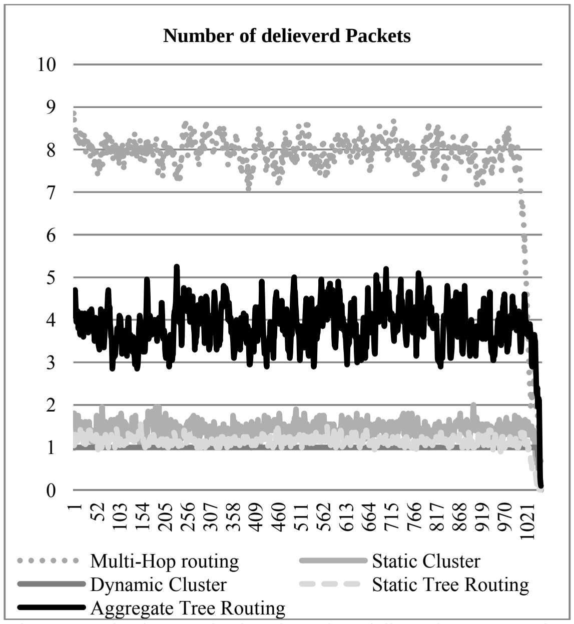

Figure 12 redundancy reductions in packets delivery in RT network

Next the figures 13:21 compare between the three proposed networks. Figure 13 shows the network lifetime of the AA, CA, and RT networks. The results show that the CA network lifetime is around 4 times the AA network and the RT network is over 8 times the AA network.

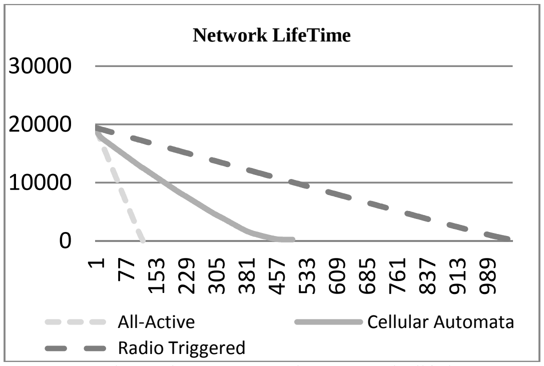

Fig. 13 the AA, CA, and RT networks lifetime

Figure 14 shows the Energy consumed by the sensing process in the three networks. The results show that the CA network consumes a minimum of 29.4% of the energy consumed in sensing a moving object in the AA network. Also the results show that the RT network only consumes at least 12.8% of the AA network sensing energy.

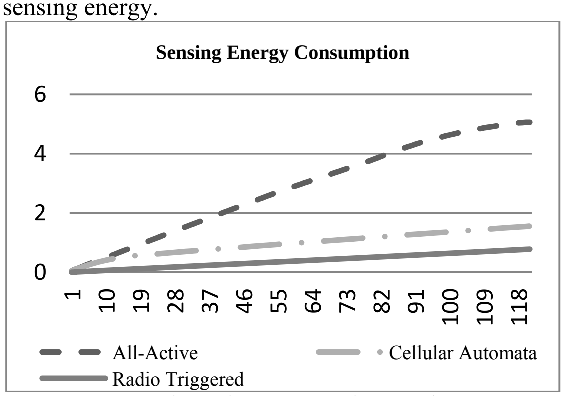

Fig. 14 the AA, CA, and RT Sensing

Figure 15 shows energy consumed by overhead communication for non-object location related messages. Results give less consumption at RT network.

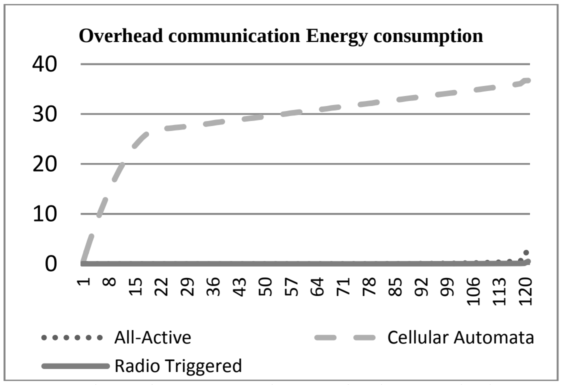

Fig. 15 the AA, CA and RT overhead communication

Figure 16 shows the Energy consumed by transmitting packets directly in the three networks recording an object's movements. The results show that the CA network consumes a minimum of 27.5% of the energy consumed in the AA network. Also the results show that the RT network only consumes 8.5% of the energy consumed in the AA network.

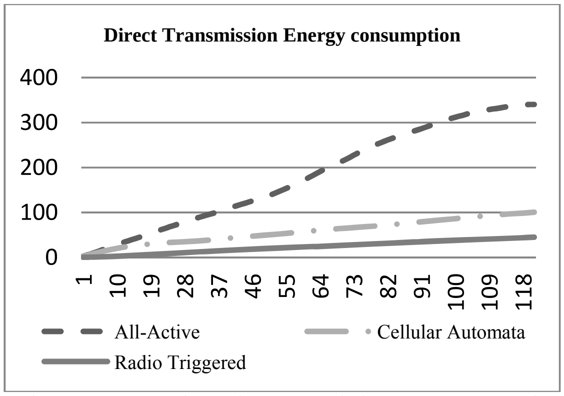

Fig. 16 AA, CA, and RT Direct Transmission Energy consumption

Figure 17 shows the Energy consumed by Multi-hop routing protocol application in the three networks recording an object’s movements. The results show that the CA network consumes a minimum of 75.4% of the energy consumed in the AA network. Also the results show that the RT network only consumes 38.5% of the energy consumed in the AA network.

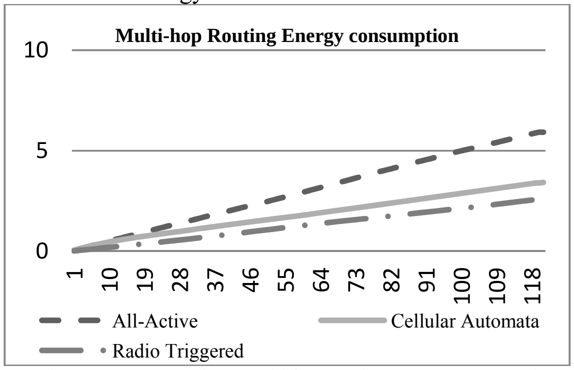

Fig. 17 AA, CA, and RT Multi-hop routing Energy consumption

Figure 18 shows the Energy consumed Static cluster based routing application in the three networks recording an object’s movements. The results show that the CA network consumes a minimum of 38.5% of the energy consumed in the AA network. Also the results show that the RT network only consumes 23% of the energy consumed in the AA network.

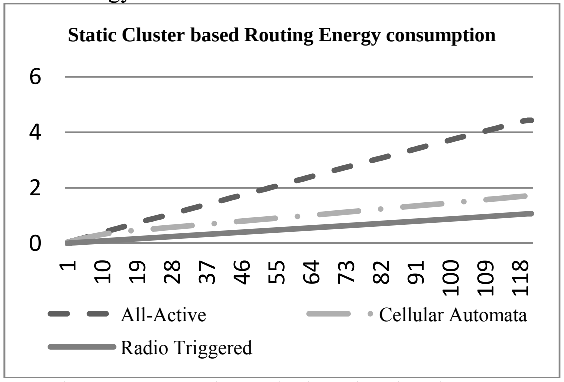

Fig. 18 AA, CA, andRT static cluster based routing Energy consumption

Figure 19 shows the Energy consumed Static Tree based routing application in the three networks recording an object’s movements. The results show that the CA network consumes a minimum of 38% of the energy consumed in the AA network. Also the results show that the RT network only consumes 21.8% of the energy consumed in the AA network.

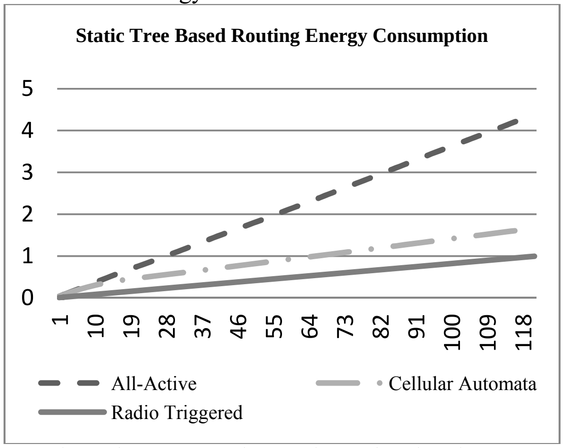

Fig. 19 the AA, CA, and RT Static Tree based routing Energy consumption

Figure 20 shows the Energy consumed Aggregate Tree based routing application in the three networks recording an object’s movements. The results show that the CA network consumes a minimum of 50.9% of the energy consumed in the AA network. Also the results show that the RT network only consumes 28.7% of the energy consumed in the AA network.

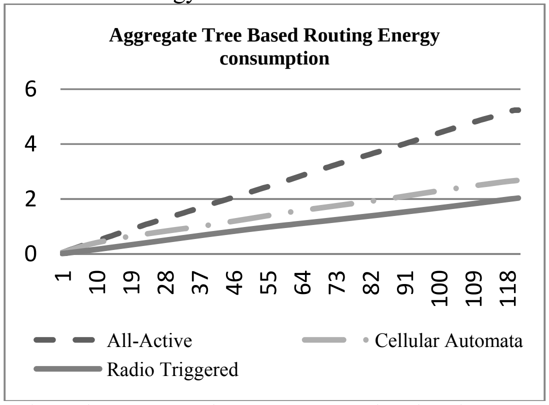

Fig. 20 the AA, CA, and RT Aggregate tree based routing Energy consumption

Figure 21 shows the Energy consumed Dynamic cluster based routing application in the three networks recording an object’s movements. The results show that the CA network consumes a minimum of 34.6% of the energy consumed in the AA network. Also the results show that the RT network only consumes 17.1% of the energy consumed in the AA network.

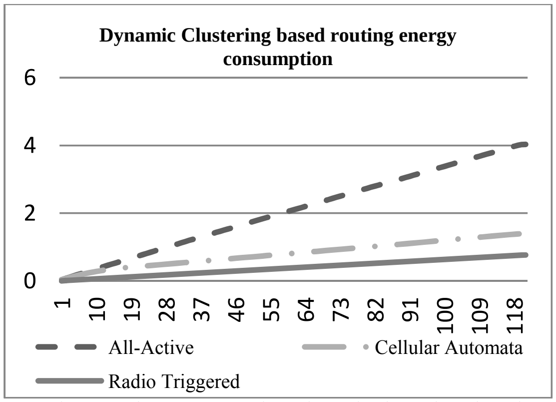

Figure 21 the AA, CA, and RT dynamic cluster based routing Energy consumption

7. Conclusion

In this paper, we have presented an approach to manage large wireless sensor networks based on cellular architecture. This approach allows us to create scenarios with a huge number of sensor nodes. It also provides scalability in order to insert new nodes in the network during its execution time with minimal overhead energy consumption due to the inheritance feature provided to each sensor joining the cellular network. The architecture proposed also allows fault tolerance in case of nodes failures for any abnormal or environmental situations. Data communication through the cellular architecture has been addressed through locating moving object application.

Two energy aware solutions have been applied to the proposed cellular architecture, organizing sensors operational states, in order to prolong the network lifetime. The suggested solutions also reduce the redundancy and communication over head through the network. The first solution applies cellular automat rules, CA network, to the cellular architecture. And the second solution depends on a radio trigged sensor nodes to be applied to the network area, RT network.

Tracking Moving object application has been suggested to test the cellular architectures performance. Routing algorithms has been specially designed to work through the cellular architecture and benefits of the inheritance feature that can be used in the network cells. All Multi-hop, Static Tree, Aggregated Tree, Static cluster, and dynamic cluster based routing protocols have been designed.

A simulator has been developed to measures the performance of the suggested architectures. The obtained results compare between the three proposed architectures for overhead communication, sensing and routing protocols for tracking moving object through the network.

The results indicate that the radio triggered proposed architecture gives the longest network life time with less communication and less overhead cost over the all active and the cellular automata architectures.

Also a comparison between all the routing algorithms has been performed indicating a lowest routing energy consumption with best redundancy reduction for the dynamic cluster based routing protocol.

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