Routing protocols and quality of services for security based applications using wireless video sensor networks

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Routing Protocols and Quality of Services for Security Based Applications Using Wireless Video Sensor Networks

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Abstract

Wireless video sensor networks have been a hot topic in recent years; the monitoring capability is the central feature of the services offered by a wireless video sensor network can be classified into three major categories: monitoring, alerting, and information on-demand. These features have been applied to a large number of applications related to the environment (agriculture, water, forest and fire detection), military, buildings, health (elderly people and home monitoring), disaster relief, area and industrial monitoring. Security applications oriented toward critical infrastructures and disaster relief are very important applications that many countries have identified as critical in the near future. This paper aims to design a cross layer based protocol to provide the required quality of services for security related applications using wireless video sensor networks. Energy saving, delay and reliability for the delivered data are crucial in the proposed application. Simulation results show that the proposed cross layer based protocol offers a good performance in term of providing the required quality of services for the proposed application.

Keywords: WVSNs, Environment Monitoring, Cross Layer, Intruders, Multimedia, QoS.

1 Introduction

Wireless Sensor Network (WSN) technology is becoming more and more mature and sensors are being used in many applications in the area of security (e.g., for monitoring buildings and private areas), environmental monitoring (e.g., river monitoring and flood monitoring) and e-health (e.g., heart rate monitoring of patients). Sensor networks include both discrete sensor data (e.g., temperature, passive and sound levels) and continuous multi-media flows (e.g., continuous audio and video flows).

A Wireless Video Sensor Network (WVSN) consists of a set of sensor nodes equipped with miniaturized video cameras. This type of networks is particularly suitable for applications that focus on surveillance [1]. A WVSN for mission-critical surveillance applications where sensors are deployed randomly before running the applications are considered in this paper [2].

Typical scenarios of video sensor networks based applications are security or disaster relief applications. In such applications, most of sensor nodes must move to sleep mode by updating their capture rates into a low level in the absence of events in order to save energy and extend the life time of the entire network. However, it is also highly desirable that some sensor nodes still keep a relatively high capture rate in order to act as sentry nodes in the surveillance system to better detection and to alert other active nodes to move to an alerted mode [3].

The application criticality to define an appropriate level of service for the proposed application is taken into account using different techniques [4]. For security related applications, the capture rates of the video sensors are used for measuring applications criticality. The higher the capture rate is, the better relevant events could be detected and captured. However, the higher captured rate is, the more energy is consumed. Therefore, a low criticality level indicates that the application does not require a high video frame capture rate while a high criticality level does.

Research on WVSNs focuses on data delivery critical applications, where some aspects of Quality of Services (QoS) need to be guaranteed in order to offer the required performance for the proposed applications. Each application needs specific requirements, a mission critical surveillance for monitoring the target environment using WVSN is considered in this paper. Video sensors are required to detect events within their Field of Views (FoV) and send them back to a sink to take the required operations.

Video sensors must be able to deliver the information such as video or image of the detected events from the source nodes toward a sink, offering the required performance by the proposed application. The quality of the transmitted multimedia, delay and energy are considered for the proposed application. In order to provide the required performance, there should be efficient protocols, which need to be designed for the proposed application. In this paper, the cross layer based protocol given in [5] has been extended so that it can deals with delivering multimedia over WVSNs, considering multi hops communication.

The rest of the paper is structured as follows. Section 2 outlines the related routing protocols and their drawbacks. Motivations for this paper are described in Section 3. Section 4 illustrates the proposed cross layer based protocol. WVSNs and multimedia evaluation are debated in Section 5. Simulation scenarios and results discussion are given in Section 6. Some conclusion and future work are presented in Section 7.

2 Related Work

Energy-efficient routing protocols have been proposed in the literature to deal with the limited battery life of sensor nodes in order to increase the lifetime of the network. In addition, new challenges are posed when Wireless Video Sensor Networks (WVSNs) are considered. In WVSNs, nodes consume more energy than normal WSNs and hence the lifetime of the network and quality of the delivered multimedia over multi-hop communication for WVSNs are big challenges. Based on this, energy saving (lifetime of the network), quality of the delivered videos (reliability) and delay are considered to be crucial requirements for the proposed application given in this paper.

Routing protocols using WSN and WVSNs are generally classified, based on the network structure, into flat, hierarchical and location based protocols. In the hierarchical based routing protocols, nodes are divided into different clusters with different roles. All nodes of flat routing based protocols are assigned the same role. In the location-based protocols, the geographic information of nodes is used for relaying data [6]. Cluster based routing protocols have been often preferred over other routing protocols because of the cluster based concepts. In these protocols some nodes take a role on behalf of others and hence energy can be saved and the lifetime of the network can be extended [7].

Low Energy Adaptive Clustering Hierarchy (LEACH) [8] is a self organized adaptive cluster based protocol for WSN. It uses cluster heads to distribute the energy load among the sensor nodes in the network. It is the first and most popular energy aware based protocol that is designed generally for saving energy for nodes in the WSN. LEACH protocol has some assumptions, such as (i) the sink is fixed and located far away from the sensors, (ii) the nodes in the network are homogeneous and energy constrained. (iii) The nodes located near to each other have correlated data, and nodes with enough energy can transmit data to the sink via a single hop communication. (iv) Nodes send data periodically. The key idea behind the LEACH protocol is to organize the sensor nodes into separate groups of nodes, called clusters, which are controlled by a Cluster Head (CH) [9]. LEACH protocol does not consider cross layer information to select reliable routes using multi hops whilst makes LEACH an unreliable routing protocol for large WVSNs. In addition, CHs are selected based on the equation given in [8] and then the chance of nodes dying in their early stages is high. Based on this, the lifetime of the network is decreased. This implies that the LEACH protocol is not a suitable protocol for WVSNs.

Power Efficient Gathering in Sensor Information System Protocol (PEGASIS) [10] is an improvement on the LEACH protocol, based on the chain using greedy algorithm. PEGASIS is a clustered based protocol like LEACH, nodes in the chain send and receive data with a sink using their direct neighbours, and only one node is selected to transmit data to a sink. However, the chain in PEGASIS is constructed and one node is selected to send data, while LEACH forms a cluster. Furthermore, PEGASIS sends data to its local neighbours in the data aggregation phase instead of sending it to the cluster head. The node in the chain that is nearest to the sink is selected to be a cluster head and takes the responsibility of data aggregation and sending it back to a sink. The key idea behind PEGASIS is that nodes communicate with their nearest neighbours, and this will extend the lifetime of the network by reducing the path between source nodes and a sink. PEGASIS selects the nearest node using a receiving signal and then selects the node with the least distance. Nodes in the chain are the nodes that are close to each other and form a shortest path to a sink [11]. Constructing nodes in to a chain may introduce extra overheads which decreases the lifetime of the network. Based on this, it cannot be applied for large WVSNs.

Threshold Sensitive Energy Efficient Protocol (TEEN) [12] is a hierarchical routing protocol that is designed for time critical applications in WSN. The TEEN protocol forms several groups of sensor nodes; each group is controlled by a cluster head as in the LEACH protocol [8]. However, nodes in the TEEN protocol deliver data over multi-hop communication between source nodes and a sink, compared to LEACH where data is delivered using a single hop communication [8]. The TEEN protocol outperforms the LEACH protocol as it can be used for time critical applications and the lifetime of the network can be increased using data thresholds. However it is not a suitable protocol to be used for applications which need to collect data periodically, because the data may not reach the sink if the threshold is not reached. Users cannot be updated with information about the network when data thresholds are not reached and hence it is not a suitable protocol to be used for surveillance applications based on multimedia transmission.

Adaptive Threshold Sensitive Energy Efficient Protocol (APTEEN) [13] is a hybrid routing protocol that aims to improve TEEN protocol so that it can be used for periodically data collected-based applications. The APTEEN protocol allows sensors to sense data periodically and reacts to any sudden change in the sensed attribute values by reporting these values to the cluster heads (CHs). The APTEEN protocol follows the same techniques as in TEEN for data transmission between sensor nodes and a sink. However, in APTEEN protocol, the following parameters are broadcast among nodes for the data transmission [14],[15]:

- Attributes (A): The physical parameters in which users are interested in.
- Threshold Values: Hard Threshold (HT) and Soft Threshold (ST).
- Count Time (CT): The maximum time that can be tolerated between two successive reports to be sent by a node in the network.
- Schedule: Assigning a slot time for each node in the network, such as using TDMA schedules.

Multi-hop communication is considered in the APTEEN protocol and data is delivered based on the strength of the received signals (RSSI). However, using only the RSSI metric is not good enough to select the reliable routes for delivering multimedia over multi-hop communication.

Multi-hop hierarchical routing protocol for Efficient VIdeo (MEVI) protocol [16] is designed for Wireless Multimedia Sensor Network (WMSN) applications, which send real-time videos in case of an event occurrence, e.g., temperature higher than 60 C. Thus, it is possible to avoid false-positive alarms and show the real impact of the event in the environment. The MEVI protocol relies on a hierarchical network architecture with heterogeneous nodes to reduce the overall communication overhead, maximize the network lifetime, and improve scalability and reliability. The nodes have heterogeneous capabilities and are divided into the following classes: (i) non-multimedia-aware nodes, restricted in terms of energy supply, processing and memory; and (ii) multi media aware powerful nodes, equipped with solar energy source, video camera and higher memory and processing capabilities. Users are not updated with regular information about the deployed network when data thresholds are not reached for a long period as in the TEEN protocol, which makes it a suitable protocol for applications when users need to be updated periodically with information about the target environments. In addition, the lifetime of the network is measured based on the number of rounds when nodes are still alive, which is not a realistic scenario for most of the applications using WVSNs in recent days.

It is shown from analysing the related work above that multi-hop communication along with a cross layer information based on the network condition from different layers (physical, MAC,...) for selecting the reliable routes for delivering data based on the multimedia transmission is required to enhance the required performance for different applications. In addition, nodes must be selected as CHs based on the remaining energy as this will extend the lifetime of the entire network. Furthermore, lifetime of the network must be measured based on realistic scenarios. However, as shown above, current cluster based routing protocols do not take into account all of these important design aspects in order to provide the required performance for multimedia-related applications.

3 Motivations

Most of the recently proposed protocols for WSNs consider either energy saving or reliability for the target applications, none of them have considered both performance metrics at the same time [6]. However, some applications may need to guarantee both energy saving and reliability at the same time, otherwise the applications will not fulfil their purpose. In addition, WVSNs have more challenges than WSNs as huge amount of energy are consumed when multimedia contents are transmitted over multi-hop communication. Therefore, new and very efficient routing protocols must be designed when multimedia transmissions are considered. Based on this, a new cross layer based protocol has been designed to offer the required performance for the proposed application given in this paper. In summary, the following are novel motivations in this paper:

1. Simulate mission critical surveillance applications using wireless videos sensor networks for security and monitoring the target environment.
2. Design the cross layer based protocol to meet the quality of services that need to be provides for the mission critical surveillance applications using wireless videos sensor networks
3. Show the performance of the proposed cross layer protocol for the proposed application when multimedia transmissions are considered.

4 Cross Layer Based Protocol

This section outlines the the design of the proposed cross layer based protocol. This protocol is based on the LEACH [9] and APTEEN [13] protocols for cluster heads selection and Time Division Multiple Access (TDMA) allocation. A new algorithm has been designed to select the reliable routes dynamically for transmitting data toward a sink, considering multi-hops cluster based topologies and cross layer mechanisms. More details about the proposed cross layer based protocol and its implementation in this paper are debated below. An example of the topology for cluster based routing protocols is given in Figure 1.

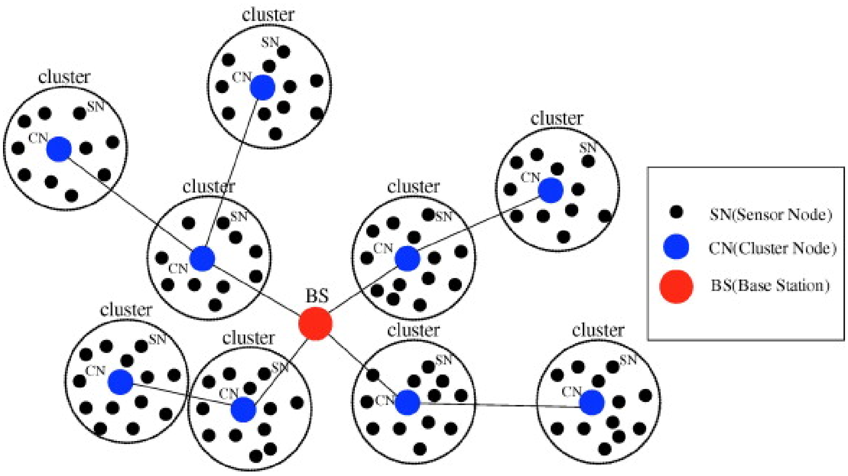

Figure 1: Cluster based topology [5]

4.1 An Overview of the Proposed Cross Layer Based Protocol

The proposed cross layer based protocol is a self-configuration and multi-hop clustering based routing protocol which has been designed for WSNs. This protocol uses a cross layer related technique to distribute energy usage between nodes over time, which conserves energy and reduces collisions. Nodes are joined into a set of different groups when they turn on their radios, each group is called *Cluster*, where nodes belonging to each cluster are monitored by a special node which is called *Cluster Head (CH)*. CHs are assigned to have more power and energy than other nodes, to deal with TDMA creation, data aggregation and data transmission. Nodes send their data to their cluster heads and then go to sleep to save energy and reduce collisions from other nodes in the network. Cluster heads receive and aggregate this data and send it back to higher cluster heads until this data is reached by a sink. Since cluster heads are selected based on their remaining energy, then the chance of nodes dying quickly is low [13].

Data aggregation using the proposed cross layer based protocol needs to be designed according to the requirements of the proposed applications. This protocol lets nodes transmit their data only when the sensed data is in the range of interest, based on the given data thresholds. This will reduce the number of unnecessary transmissions and hence allow the proposed protocol to be used for critical and non critical related applications using WSNs. After cluster heads are selected, they need to advertise themselves to the rest of the nodes in the network. After the CHs advertisement, TDMA schedules are created and broadcast so that the required slots for members can be allocated. After cluster heads are selected and TDMA schedules for members are allocated, nodes can transmit their data to their cluster heads using their allocated slots in which this data will be aggregated and send it back to a sink [15].

4.2 Details of the Cross Layer Based Protocol

The operations of the proposed protocol are divided into *rounds*, where each round starts with 4 different phases which are *set-up*, *TDMA schedules creation*, *routes discovery* and *data transmission* as shown in Figure 2. In the set-up phase, nodes organize themselves into different clusters at the different levels in the network, where each cluster needs to be monitored by a cluster head, followed by an advertisement phase. Cluster heads need to advertise themselves to the nodes in the network. Non cluster heads ask to join to different clusters, based on the different costs. In the TDMA schedules phase, different slots are allocated for non-Cluster heads to deal with data communication.

In the route discovery phase, cluster heads must find different routes for relaying data from members to a sink via a multi-hop communication. Based on this, a new algorithm needs to be implemented to select routes between CHs and a sink where different situations are considered. In the data transmission phase, nodes start to send data to their selected cluster heads over a single-hop communication and then go to sleep to save energy. More details about these operations are given below.

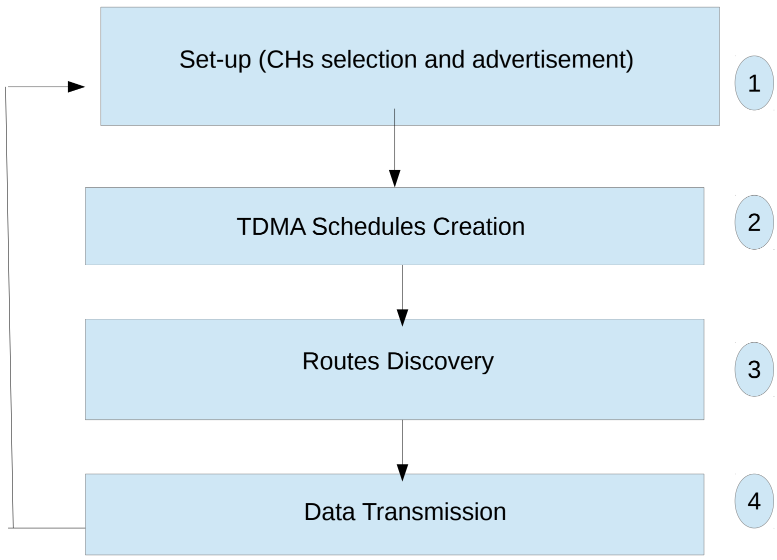

Figure 2: Protocol Operations

4.2.1 Cluster Heads Selection

As mentioned before, the proposed cross layer based protocol uses a cluster heads selection technique used by LEACH[9]. When each node turns on its radio, it needs to decide whether or not become a cluster head in the current round. This decision is based on the suggested percentage of the nodes that needs to be selected as cluster heads in the network and the number of rounds that this node has not been selected as a cluster head yet. The selection of the node n to become a cluster head in the current round depends on the probability of a random number between 0 and 1 which is denoted by (rn) and the pre-defined threshold value which is represented by $T(n)$ as described in [9]. The $T(n)$ is defined as follow:

$$T(n) = \begin{cases} \frac{P}{1-P*(r mode \frac{1}{P})} & \text{if } n \in G \\ 0 & \text{otherwise.} \end{cases} \quad (1)$$

Where *P* is a percentage of cluster heads that needs to be selected, *r* is the current round and *G* is a set of nodes that have not been selected as cluster heads in the previous *1/P* rounds. If *rn* is less than *T(n)*, then the node *n* is selected to be a cluster head in the current round *r*. One of the drawback for the algorithm used for selecting cluster heads given in [9] is that the sink does not consider the remaining energy for nodes when becoming cluster heads. Hence, nodes may be prone to die in their early stages. Based on this problem, [17] designed a new solution by considering remaining energy for nodes before becoming cluster heads, using the following equation:

$$T(n)_{new} = \begin{cases} \frac{P}{1-P*(r mode \frac{1}{P})} \frac{E_{cur}}{E_{max}} & \text{if } n \in G \\ 0 & \text{otherwise.} \end{cases} \quad (2)$$

Where E_{cur} is current energy and E_{max} is initial energy of the node *n*. This algorithm lets the sink selects nodes with the maximum remaining energy to be cluster heads in each round whilst extends the life time of the network. The implementation given in this paper is based on this method for selecting cluster heads.

4.2.2 TDMA Schedules Allocation

After Cluster heads selection, each CH needs to allocate different slots for their members using TDMA schedules, to let their members deal with data communication using their allocated slots. It has been assumed that a sink creates and sends queries to different parts of the network and then nodes reply as soon as they have data matching the query. So in some cases, nodes need to have different slots to deal with query and data transmissions. In addition, CHs need to have their own slots for finding routes and aggregating data. Based on these requirements, TDMA schedules for the proposed protocol are classified into five types of slots: slots for data transmission, slots for answering queries, slots for finding routes, slots for aggregating data and slots for deal with multimedia related traffics. A sink should not ask nodes to answer a query at the same time as they are transmitting their own data [13]. Therefore, a TDMA schedule using the cross layer based protocol consists of the following fields:

1. **Member Slots:** Each cluster head creates a TDMA schedule for each member using *TX,QA* slots. Each member is active only at its allocated slots. A TX slot is used for transmitting data while QA slot is used for answering queries.

2. **Aggregation Slots (AG):** Cluster heads use these slots to aggregate data from their members.

3. **Route Discovery (RD) Slots:** Cluster heads use these slots to discover routes between nodes when transmitting aggregated data from their members toward a sink.

4. **TX Slots:** Cluster heads use these slots to transmit their own data toward a sink.

5. **Multimedia Slots** (MS): Cluster heads use these slots to send multimedia to a sink.

The allocated TDMA schedules allow members from the different clusters to deal with data communication only in their allocated slots and then go to sleep in the rest of the frame. This saves energy and avoids collisions from the other nodes in the network. When mobility is considered, new algorithms need to be designed to update TDMA schedules according to new attachments. By combining all these factors, a TDMA schedule for the proposed protocol can be defined as shown in Figure 3.

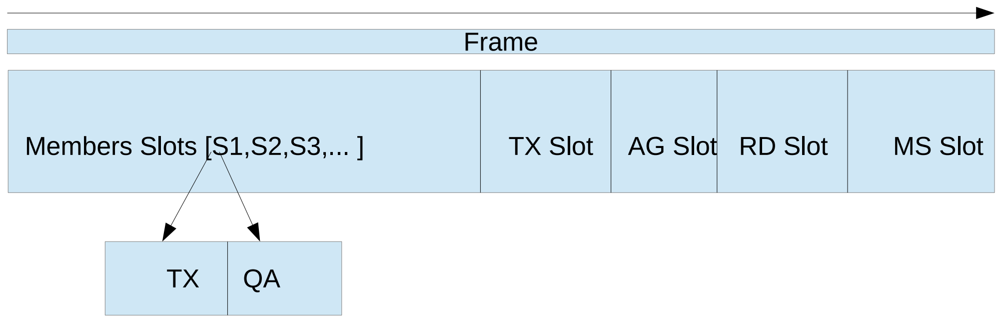

Figure 3: TDMA Schedule Structure

4.2.3 Multi-hops Clustering and Routes Selection

The required algorithm for selecting routes over multi-hops communication between different nodes in the network was not described in the specifications given in [15], so a lot of options were considered when this protocol was implemented. A new module to select routes, considering multi hops and different cross layer based information has been designed. This module considers the remaining energy, location and RSSI for selecting reliable routes to forward data toward a sink.

While the sink has global information about all nodes in the network, such as remaining energy and locations, then in this implementation, the sink is assumed to be responsible for dividing the deployed network into different levels. Based on this, nodes close to the sink are selected as *Higher level-based nodes* in which communicate with a sink via a single hop communication. However, nodes far away from the sink are selected as *Low level-based nodes*.

Nodes on the low level in the network must select the higher level based nodes (CHs) to relay their data toward a sink, based on the following three link costs: remaining energy, distance and RSSI. Based on these metrics, the routes for delivering data are selected between nodes. Since only cluster heads are involved in the routes selection, then the energy consumption can be optimized, by simply forcing the rest of the nodes to go to sleep.

Routes Selection Algorithms New algorithms such as 4.1 and 4.2 have been designed to select reliable routes for data transmission after cluster heads selection. Nodes are classified into 3 different types in the proposed algorithms which are sink (SINK), CHs and Sensor Node (SN) as shown in the given algorithms. The proposed routes selection algorithms provide valid routes between nodes such as cluster heads and a sink, CHs themselves and CHs and members. Nodes check first if they have valid routes before sending data. In the case where no routes are available, then nodes ask for urgent routes from their neighbours to send their data as soon as possible.

Algorithm 4.1: ROUTES DISCOVERY($N, CH[], grid, MaxHop$)

```
comment: Finding routes to deal with data communication for node N
comment: CH[]: is a set of available CHs for current node
comment: grid: size of the deployed network
comment: MaxHop: maximum hops
comment: SN: Sensor Node (Member)
if N is SINK
  then { for J ← 1 to CH[].SIZE
           do { F[J]←FALSE
                d[J]←0
                for I ← 1 to MaxHop and not F[J]
                  do { d[J]←d[J]+grid/MaxHop
                       if CH[I].distance≤d[J]
                         then { CH[I].level←I
                                F[J]←TRUE
                                if CH[I].level≠MaxHop
                                  then { if CH[I].level == 1
                                         CH[].nextHop←SINK
                                         P←new ADV(CH[I])
                                         Broadcast P
                         else
                         then d[J]←d[J]+grid/MaxHop
  else if N is Cluster Head (CH)
  then { if ReceiveADV(CH1,CH2)
           then CH.NextHop←NEXT HOP(CH,CH1,CH2)
  else if N is SN (Member)
  then {SN.NextHop←NEXT HOP(N,CH1,CH2)
```

Algorithm 4.2: NEXT HOP($N, CH1, CH2$)

comment: Finding next hop for node N

comment: RSSI:Receiver Strength Signal Indicator

comment: RE:Remaining Energy

comment: DIST:Short Distance from CHs

if CH1.RSSI≠CH2.RSSI
  then return (MAX(CH1.RSSI,CH2.RSSI))
  else if CH1.RE≠CH2.RE
  then return (MAX(CH1.RE,CH2.RE))
  else return (MIN(CH1.DIST,CH2.DIST))

4.2.4 Data Transmission

After cluster heads are selected and TDMA schedules for members are allocated, nodes can transmit their data to their cluster heads using their allocated slots in which then this data is aggregated and send it back to a sink. The proposed cross layer protocol deals with data communication based on scalar data and multimedia related transmissions when delivering information about the detected events from source nodes toward a sink as shown below:

- Nodes belong to different clusters (non-cluster nodes) sense the target environments and send their information back to their CHs via a single hop communication and then go to sleep.
- CHs then aggregate this information and send it back to a sink over multi-hop communication. Scalar or multimedia transmission are considered based on the required application.
- Sink extracts this information and replies directly to source nodes which detect the events in case needed.

In summary, the cross layer based protocol has the following capabilities to offer the required performance for the proposed application given in this paper:

- By sending query over time to the different parts of the network, users can have a complete picture of the network, which most of the recently cluster based routing protocol do not have this feature.
- It can be used for critical and non critical delivered data related applications by using different thresholds. This allow users to choose thresholds according to the requirements of the proposed applications.
- Energy can be conserved by distributing energy usage between nodes in the network.
- Delay can be decreased and energy can be conserved by aggregating and reducing redundant copies of data at the intermediate nodes in the network.

- Nodes in each cluster need only send their data to their cluster heads over a single hope communication using their allocated slots, so lifetime of the network is extended.
- Only cluster heads are involved for routing and forwarding data toward a sink, this reduces the routing complexity in large WSNs.
- Only cluster heads need to aggregate data from their members thus saving energy.
- Data is transmitted toward a sink using the best available links based on the different link costs, such as Receiver Signal Strength Indicator (RSSI) and remaining energy.
- Proposed cross layer protocol combines information from different layers such as MAC, Radio (CC2420), physical (IEEE 802.15.4) and routing layers for selecting the reliable routes for data transmission from source nodes to a sink. Based on this, the required performance can be optimized.
- Only cluster heads are involved for multimedia transmissions.

5 Wireless Video Sensor Network and Multimedia Evaluation

5.1 Wireless Video Sensor Networks

A Wireless Video Sensor Network is a WSN where each node is equipped with a small camera to capture the environment; each video sensor needs to sense the environment within its field of view to detect events and then alert its neighbours about the detected events as soon as possible. WVSN may need huge amount of energy when delivering multimedia to a sink considering multi hop communication. This implies that there should be some energy-aware algorithms to let nodes save energy in the absence of events. Based on this, the notion of *cover set* has therefore been introduced to define the redundancy level of a sensor. Sensors cover the same part of the networks for *k* nodes is called $k - coverage$ [1]. WVSN needs to use its maximum capture rate just in case needed and hence there should be some techniques that allow sensors to use their capture rates as desired based on the requirements of the proposed application. The higher the capture rate is, the more energy is consumed [3].

Different parts of the area of interest may have different risk levels according to the pattern of the observed events such as the number of the detected events. So sensors deployed in each part need to be identified with two different levels of critically, which are *low critical* and *high critical* levels. A low criticality level indicates that the target application does not require a high video frame capture rate to save energy while a high criticality level does. More details about the cover sets calculation and level of critically related issues are described below [4].

5.1.1 Video Sensor Coverage Model

Due to the dynamical network topology changes using WVSNs, a lot of challenges are carried out, such as fault-tolerance and increasing the lifetime of the network. In randomly deployed sensor networks, provided that the node density is sufficiently high, sensor nodes can be redundant (nodes that monitor the same region). This leads to overlap among the monitored areas and also some parts of the network may be uncovered. Therefore, a common approach to avoid this is to define a subset of the deployed nodes to be active while the other nodes can sleep [2]. One possible solution for this issue is to let some nodes go to sleep when there are other nodes, which cover their sensing area. This implies that there should be some efficient scheduling algorithms to let nodes dynamically go to sleep based on the number of their available neighbours.

In security related applications based on WVSNs, some part of the deployed environment may have more level of risk than the others, for instance number of detected intruders. Hence, nodes are required to be active and use all of their capability to sense the environment when required. This is a problem since nodes will consume all of its energy while capturing the environment using their maximum capture rates. Author in [2] proposes an efficient solution for this case, which is called *covered set*.

Cover set for node n is denoted by CoV(n) and can be calculated as follows: *CoV(n)* = {*v1,v2,v3,..,vm*}, where Field of View (FoV) for each node in set {v1,v2,..,vm} covers different parts of FoV of node n as described in Figures 7 and 8. Nodes need to calculate their cover sets based on their available neighbours and then decide if they need to be active or not. When mobility is considered, cover sets need to be updated for each mobile node periodically. The Author in [4] described how cover sets for each node can be calculated and then based on this, nodes decide when to be active. Video sensor nodes use their capture rates based on the length of their cover sets. Nodes with maximum cover sets use their maximum capture rates. Based on this, a Bezier curves algorithm as shown in Figure 4 and given in [2] has been designed. More details about WVSNs, Bezier Algorithm and cover sets calculation related issues can be found in [18].

5.1.2 Critically Based Schedules in WVSNs

Authors in [2] and [4] have suggested novel methods, which enable nodes use their capture rates based on their neighbours and critical levels of different parts of the target environments. This decision can be made based on the *Bezier curve* as described in Figure 4. The Author in [4] shows that it is desirable that most sensor nodes move to a so-called *hibernate mode* or sleep mode in the absence of events in order to save energy. On the other hand, it is also highly desirable that some sensor nodes still keep a relatively high capture rate in order to act as *sentry nodes* in the surveillance system to better detect intrusions/events and to alert other active nodes to move to an *alerted mode*. These nodes can be replaced by their cover sets in case damaged or died. With video sensors the higher the capture rate is, the better relevant events could be detected and identified.

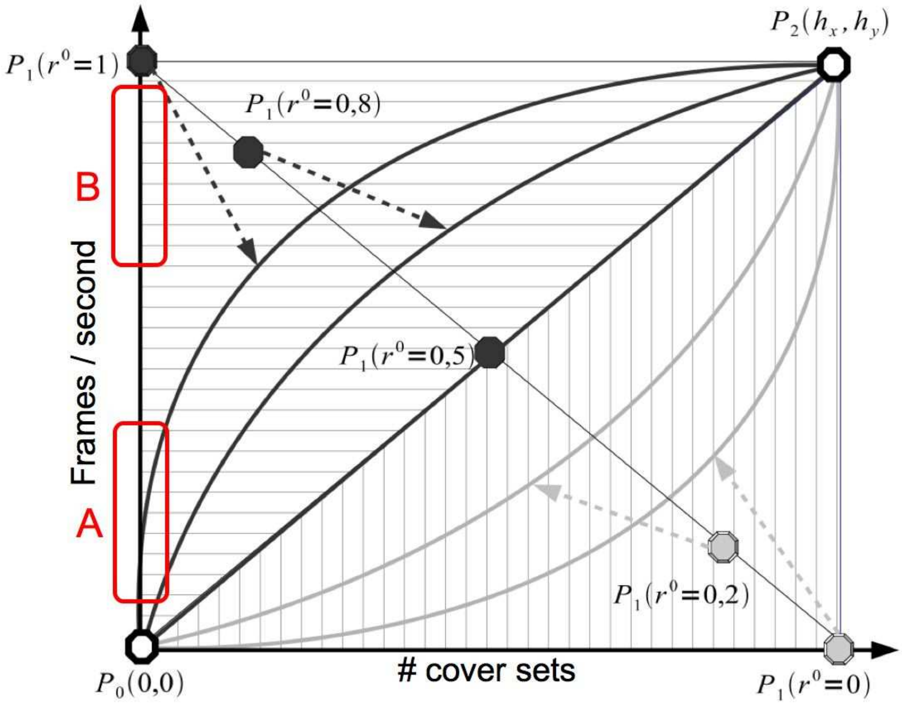

Figure 4: Define the critically for different parts of the interested area [2]

A common approach using the Bezier algorithm using WVSNs is to define a subset of the deployed nodes to be active while the other nodes can sleep. The idea implies that when a node has several covers (neighbors), it can increase its frame capture rate to act as a sentry node because if it runs out of energy it can be replaced by one of its covers. Then, depending on the applications criticality, the frame capture rate of those nodes with a large number of cover sets can dynamically be changed [18].

As shown in the Figure 4, Bezier curves [4] can be used to compute dynamically the level of criticality for different parts of the interested area as required by the application using only three points (P0, P1 and P2). The level of criticality for the proposed application can be defined using two levels, which are high criticality ($r > 0.5$) and low criticality ($r < 0.5$). These levels are defined by P0, P1, and P2 as shown in the Figure 4. Point P0 (0, 0) is the origin point, P1 (bx , by) is the behaviour point and P2 (hx, hy) is the threshold point where hx is the highest cover cardinality and hy is the maximum frame capture rate determined by the sensor node hardware capabilities [19].

When video sensor has maximum cover sets, it can use its maximum capture rate (r=1) as shown in Figure 4) for better detection and use lowest capture rate (r=0) to save energy when no events are happening. This implies that capture rates for video sensors can be changed from a lowest rate to a highest rate using Bezier curves based on the criticality of the proposed application (from rectangle A to rectangle B, as shown in Figure 4). Some examples have been given in [2] to show how *Bezier curve* can let camera nodes increase their capture rates based on the level of different critical events and number of their cover sets.

5.2 Multimedia Management and Evaluation using WVSNs

5.2.1 Multimedia Management

Applications involving multimedia transmission over WVSNs must evaluate the video quality level from the users perspective, and also collecting video-related characteristics. Videos can be represented by frames with different priorities (I, P and B) compose a compressed video, and the loss of high priority frames causes severe video distortion from humans experience. Some of these frames have direct impact to the quality of the delivered multimedia while others have less affect [1]. First, for the loss of an I-frame, the errors propagate through the rest of the Group of Picture (GoP), because the decoder uses the I-frame as the reference frame for all other frames within a GoP. When this occurs, the video quality recovers only when the decoder receives an unimpaired I-frame. Second, for the loss of a P-frame, the impairments extend through the remaining of the GoP. Third, the loss of a B-frame affects the video quality only of that particular frame [2].

In this context, multimedia flows enable the end-users (systems) to visually determine the real impact of a detected event, performing object/intruder detection, and analyse the sensed events based on collected visual information using WVSNs. However, Castalia [20] and its extensions (both WiSE-MNet and WVSN models) do not enable the transmission, control and evaluation of real video sequences. Therefore, a new framework, which is called *M3WSN* as shown in [21] has been designed for multimedia management and evaluations over WVSNs based on Evalvid [22]. The overall architecture of the M3WSN framework is given in Figure 5.

The Evalvid framework provides video-related information, such as frame type, received/lost, delay, jitter, and decoding errors of the received or distorted videos. This video-related information enables the creation of new assessment and optimization solutions for fixed and mobile nodes involving multimedia related scenarios. Evalvid can be used for video transmission and quality evaluation based on some videos sequences and traces. Thus, before transmitting a real video sequence, video sources, for example from a video library [23] must be provided in advance.

5.2.2 Encoding and Decoding Multimedia Contents

Once the video has been encoded, trace files have to be produced at both sender and receiver sides. The trace files contain all relevant information for transmission, and the evaluation tools provide routines to read and write these trace files for multimedia evaluation. Specifically, there are 3 kinds of trace files. Two of them are created at the source side, namely video and sender traces. On the other hand, the destination node creates the receiver traces. Both sender and receiver traces are required to generate the trace files over multi-hop communication using WVSNs. These trace files and original video are used at the final destination to reconstruct the transmitted video. More information on how to create these trace files can be found in [21].

The video trace is created once, and contains all the relevant information about every frame that comprises the video. Sender traces at the sensor are created at manager module level using the framework given in [21], because it supports a camera retrieving a video. On the other hand, the receiver trace is created at the application layer module, as it represents the application layer receiving multimedia packets and reconstructing the video at the final destination (sink). Moreover, the user can define the energy consumption rate for retrieving each frame, and this

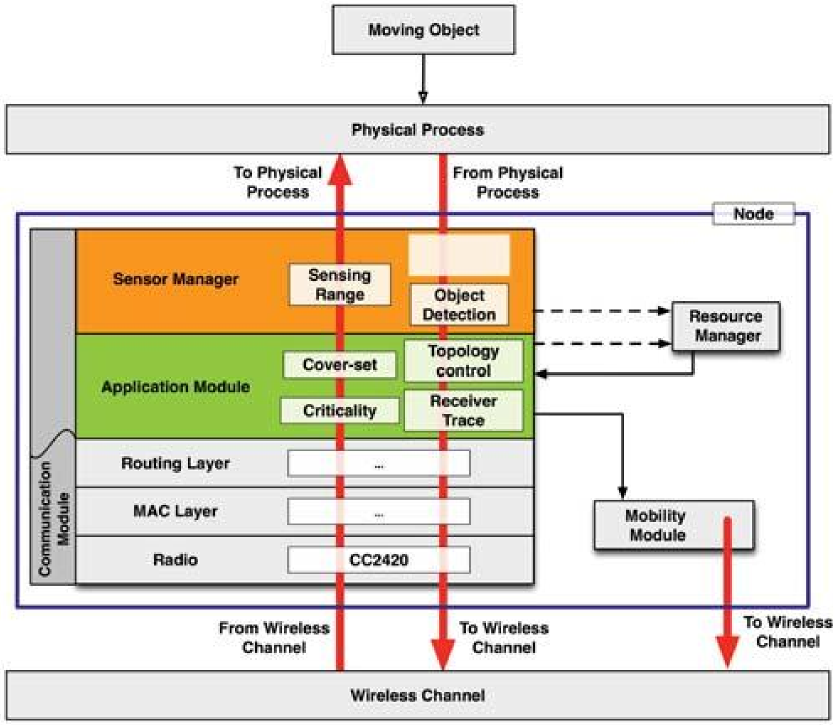

Figure 5: Overall structure of the M3WSN framework [21]

value could be chosen for a real camera. Practically real values for energy consumption should be obtained by measures on real hardware

The framework given in [21] can be used for measuring different quality of services regarding each transmitted video at the destination side, such as delay, loss rate for the transmitted frames along with the overall of the loss rate of the transmitted videos. Users can easily use these methods to analysis the required performance of different applications using WVSNs.

6 Performance Evaluation

6.1 Simulation Scenarios

The proposed cross layer based protocol and LEACH [8] protocols using different scenarios for the proposed application are simulated in this paper. Simulation parameters for all scenarios are given in Table 1. Each sensor node is defined by its position (x,y), a depth of view for the camera, a line of sight for the camera and an angle of view (AoV). The sensors field of view is then represented by a triangle as shown in Figure 7. The LEACH protocol has been selected in this paper as it is one of the cluster based routing protocols which aims to save energy using WSNs. LEACH protocol has been modified so that it can deal with multimedia transmissions. More details about the proposed application is given in Section 6.2.

Simulation is conducted to analyse the performance of the proposed cross layer based and LEACH protocols for the multimedia management using framework given in [21]. This framework is a good module to evaluate transmitted videos over WVSNs using different protocols. The M3WSN framework efficiently defines a model to find subsets of nodes to cover a given area and defines the sensing range by a FoV as shown in Section 5. The Evalvid framework

Table 1: Simulation Parameters

Parameter	Value
Field Size (Scenario1)	50m X 50m
Field Size (Scenario2)	50m X 100m
Field Size (Scenario3)	150m X 100m
Field Size (Scenario4)	200m X 200m
Protocols	CrossLayer and LEACH
Number of nodes (Scenario1)	50
Number of nodes (Scenario2)	100
Number of nodes (Scenario3)	200
Number of nodes (Scenario4)	1000
Percentage of CHs	5-15
Round duration	20 seconds
Duration of each slot	1 seconds
Location of Base Station	(0,0)
Number of intruders	1-4
Temperature Threshold	48
Transmission Power for LEACH	0 dBm
Transmission Power for CrossLayer	-10 dBm
Radio	CC2420
Radio Propagation Model	Log-normal Shadowing
Video sequence	Hall
Video encoding	MPEG-4
Number of frames for each Video	300
Video format	QCIF(174 x 144)

[22] provides support for the transmission, control and evaluation of real video sequences in simulation environments as shown in Section 5.2. Critical sensor management and cover sets discovering modules are implemented in the same framework. This lets video sensors capture the environment and send multimedia content when it is needed, for example, when intruders are detected or very high temperature is sensed.

The application architecture given in Figure 6 is considered in this paper to show the impact of different routing protocols for delivering multimedia from the detected events to a sink, performing the required performances, such as quality of transmitted videos, delay and lifetime of the network. For this paper, the video sequence was chosen from the Video Trace Library [23]. This video uses the QCIF format as it is more suitable for WVSNs, as shown in [2].

The hall monitored video sequence was chosen from the Video Trace Library [23] in this paper as it is more suitable for monitoring related applications such as intrusion detection related applications. According to [2], hall video sequence is measured as a high movement video, which is more suitable for the proposed application given in this paper. Hall video contains two targets moving in the hall and based on this movement, both routing protocols are measured.

Routing protocols are usually evaluated from network and packet level point-of-view by using QoS metrics, e.g., delay, jitter, or loss. However, QoS metrics do not reflect the users perception and, consequently, fail in capturing subjective aspects associated with human experience when multimedia need to be considered [16]. Quality of Experience (QoE) metrics (PSNR, SSIM, VQM,..) and approaches overcome the limitations of current QoS-aware routing schemes regarding to human perception and subjective-related aspects [3]. Therefore, to highlight the impact of using the proposed routing protocols given in this paper, from the user point-of-view and to measure the quality of the delivered videos, the simulation evaluates transmitted videos by considering both PSNR metric [16] and delivered frames [21]. EvalVid and M3WSN frameworks are used for measuring the quality of the delivered videos. The PSNR metric has values ranging from 0 to 41, the higher value means the better video quality as shown in Table 2.

Table 2: PSNR evaluation values [16]

Number	Value
40.0 - 40.1	Excellent
37.0 - 39.9	Very Good
31.0 - 36.9	Good
20.0 - 29.9	OK
0 - 19.9	Bad

Four different scenarios for the proposed application based on the realistic scenarios are considered in this paper. The first scenario consists of deploying nodes in a small field (one floor-based security environment) so that all nodes can communicate with a sink using a single hop communication. The second scenario is a network where source nodes are far away from the sink so multimedia contents cannot be delivered using a single hop communication (two floors-based security environments). The third and fourth scenarios are very large scenarios where data needs to be delivered over long routes between source nodes and a sink (more than two floors-based security environments). In all scenarios, the cross layer based protocol and LEACH were measured in term of delivering the multimedia contents from different parts of the network for the proposed application given in Section 6.2.

6.2 A Proposed Application

6.2.1 A Security Applications based on Multimedia Transmission

Security related applications [1] are monitoring related applications in WVSN when events are detecting by video sensors in the target environments and then sending information back to a sink to take the required decisions. A WSN is a best solution to be used for these applications because of the following two main features: (i) capabilities of WSNs for sensing and collecting data from the deployed environments and then sending back to a sink. (ii) Low cost for individual sensor so in case some nodes have died, other nodes or sensors can replace them. In this case, a WSN needs to be able to configure itself when some nodes are out of energy, to keep the network well connected.

Cluster based WVSN architecture of different levels or ties for the event detection applications is considered in this paper. An example of the proposed application is given in Figure 6, which consists of two types of nodes, scalar and camera nodes. Scalar sensor nodes perform simple tasks, such as detecting scalar physical measurements and resource rich camera sensors are responsible for complex tasks, such as sending the multimedia from the detected events to a sink when required.

The scalar sensor nodes have a limited sensing range to sense scalar physical data from the target environments to detect events if there is any, based on some physical measurements, such as temperature, humidity, vibration and so on. On the other hand, camera sensors nodes are responsible for capturing the detected events using their equipped camera in the positions where these events are detected and then send back the multimedia representing these events to a sink. In this case, scalar sensors have to wake up and alert camera nodes when any events are detected.

In the proposed application, nodes are assumed to be multi-features, for example, nodes can sense the environment and do security at the same time. In this case, nodes are assumed to sense the environment using temperature measurement and also do security by sensing vibration measurement of the objects moving around, and inform the sink when one of these events is occurred.

Target intruders in the proposed application are mobile and can move randomly in the monitored environment. Source sensor nodes sense the environment within their range of sensing and then wake up the camera nodes when events are detected as previously discussed. Camera sensor nodes capture the detected targets after receiving alert messages from their members using their FoVs. Thus, the sensing range of a camera node is limited, and depends on the direction of the camera and its features for angle and depth of view intruders or alarmed area can be captured and monitored.

A lot of approaches have been carried out to show how intruders can be covered considering different points of the FoV for camera nodes when sensing the target environments. Two approaches have been recently proposed in [2] and [1] using WVSNs. The first approach is considering a camera node with a FoV covering only one gravity point (g) with different angles. In this approach, a FoV with bigger angles can detect more intruders as shown in Figure 7. However, the second approach is considering a FoV with several alternative gravity points (g_1,g_2,..) as given in Figure 8. The Author in [2] suggests that the second approach is often preferred because FoV with more alternative points can have more cover sets and then detect more events.

When a camera node receives the wake-up message from scalar sensors, it should change the direction of its FoV to the location where events are detected and then retrieve video from the alarmed target area as shown in Figure 6. A captured multimedia for detected events can provide users with more precise information and allow them to decide suitable actions in real time, which is better than scalar data where detected events may be inaccurate. In addition, the transmitted videos are useful to monitor, detect and predict the intruders moving directions so that the proper real decisions can be made in advance. An example of the intrusion detection based application using WVSNs is given in Figure 6, the same application is considered in this paper.

Multimedia security related applications require high video quality from the user perspective, scalability, energy efficiency and low network overhead. Therefore, in order to efficiently transmit video packets under certain application level requirements over multi-hop communication, efficient routing protocols must be designed. Based on these required critical, this paper aims to design a cross layer based protocol to manage multimedia over WVSNs, considering the required performance for the proposed application.

The proposed cross layer based protocol can provide suitable communication architecture for the application scenario that is described above. A multi-hop communication with a cross-layer information to select different routes based on the network conditions such as link quality, remaining energy and hop count are considered in the proposed protocol. Camera sensor nodes are considered to be CHs and scalar sensor nodes are assumed to be members in each round. This implies that each cluster head has basic information about their members such as location and remaining energy. Camera sensor nodes are selected to be CHs based on their remaining energy as this extends the lifetime of the entire network. This information can also be used by CHs when receiving wake up messages from their members, to change their FoVs to the target and alarmed area in order to capture the pre-detected events.

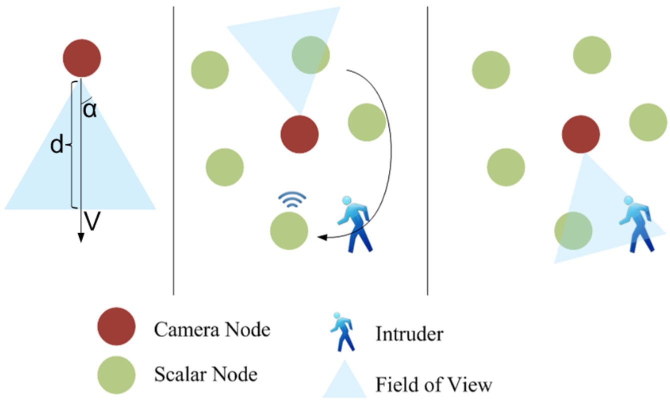

Figure 6: Typical Scenario for the security related applications using WVSNs [4]

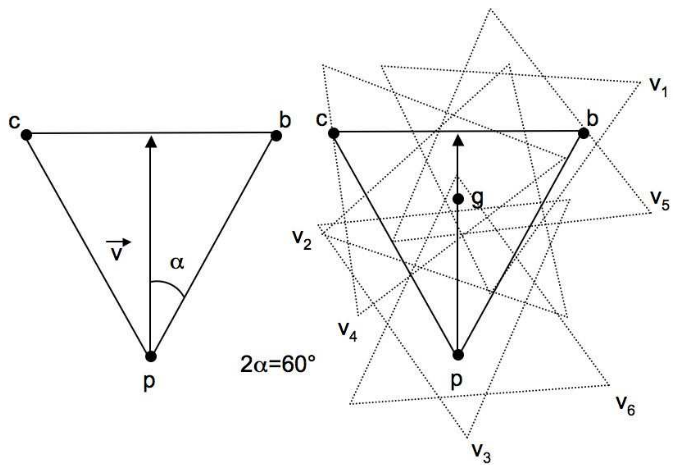

Figure 7: Field of view for sensor camera nodes having one gravity point (g) [2]

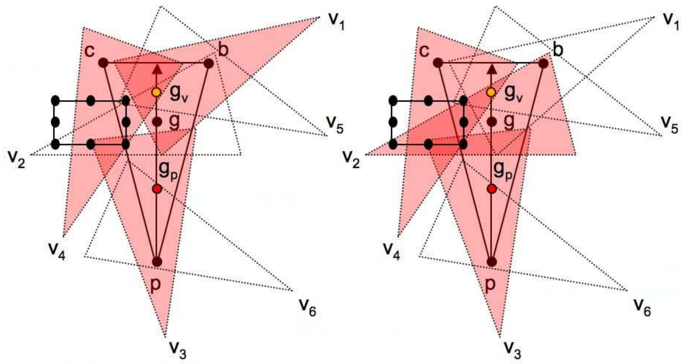

Figure 8: Field of view for sensor camera nodes having alternative points (g,g_v,g_p) [2]

6.2.2 Quality of Services for the Proposed Application

In this paper, the target environment is assumed to be monitored by sensing temperature and doing security at the same time. Intrusions are assumed to be generated at the different parts of the network over time and then move randomly to different locations automatically. When each sensor node detects an intruder or senses abnormal temperature form the target environment, it must collect information about the detected event and then sends this information back to a sink with high quality while consuming less amount of energy. Based on this, the following features are required for the proposed application:

1. **Lifetime of the Network:** Lifetime of the network for the proposed application can be defined by total number of active nodes over time, so nodes need to be active only in case needed in order to extend the lifetime of the network. The lifetime of the network can be extended using cover set related algorithms when nodes have shared cover sets with other nodes they can simply go to sleep [18]. However, lifetime of the network has been defined recently using different concepts based on the realistic scenarios as shown in [5]. Based on this, in the proposed application, the lifetime of the network is the maximum time that a WSN can survive, whilst spending energy at a given rate. Let total consumed energy by each node be denoted by *C* joules, initial energy by *E* joules and current simulation time by *T* seconds, then the lifetime of each node (except sink which is assumed to have unlimited power) in the network has been calculated as given in 3.

$$Lifetime\_node(n)(indays) = ((E/C) * T)/86400 \tag{3}$$

Where *86400* is number of seconds in each day and (E/T) is an average of consumed energy in a second by node n. In this way, the lifetime of the entire network is assumed to be an average of the lifetime for all nodes in the network as given in 4.

$$Lifetime\_network(indays) = \frac{\sum_{i=1}^{k} Lifetime\_node(i)}{k} \tag{4}$$

Where *k* is number of nodes in the network.

2. **Quality of the Delivered Videos:** When an event is detected in the proposed application then multimedia representing this event must be delivered to a sink with the required

quality by the proposed application. Some applications may accept low quality for the received videos while others accept only videos with high quality. In the proposed application, the quality of the received videos needs to be clear enough so that the required actions can easily be taken. Quality of the delivered videos is calculated as shown in 5 and 6, respectively.

$$Quality(PSNR) = \frac{\sum_{v=1}^{V} PSNR(v)}{V} \tag{5}$$

$$Quality(Frames) = \frac{\sum_{v=1}^{V} (v\_I + v\_B + v\_P)/3}{V} \tag{6}$$

Where V is number of delivered videos at the destination (sink), v_I, v_B and v_P are frames for the delivered video (v) with corresponding types, respectively. $PSNR(v)$ is psnr value for the transmitted video (v).

3. **Delay for the Delivered Videos:** Videos for the detected events must be delivered to a sink within the minimum delay so that events can be captured and detected using the proper actions, before any further risks can be happened.

6.3 Results Discussion

Different scenarios for the proposed application using the proposed cross layer based protocol and LEACH, where life time of the network, quality of the delivered data and delay are crucial, have been simulated in this paper as shown in Section 6.1. Simulation results are discussed in the following sections.

6.3.1 Quality of the Transmitted Videos

Figures 10 and 9 show the performance of the proposed cross layer based protocol and LEACH using different scenarios for the proposed application based on PNSR and delivered frames, respectively. The video quality varies depending on the distance between locations of detected events and a sink. In this case and as shown in Figures 9 and 10, both LEACH and proposed cross layer based protocols deliver multimedia from source nodes to a sink in a very good quality when small networks are considered. CHs in this case can communicate with a sink using a single hop communication (first scenario). The reason behind this behaviour is that for single-hop communication the camera nodes or cluster heads send multimedia packets using single hop transmission. A sink is in the transmission range of such nodes to receive packets with higher reliability and then improve quality of the delivered videos. Based on this, both LEACH and proposed cross layer based protocols deliver multimedia with a very good quality (an average of 100% of frames and PSNR = 40) from the detected events to a sink.

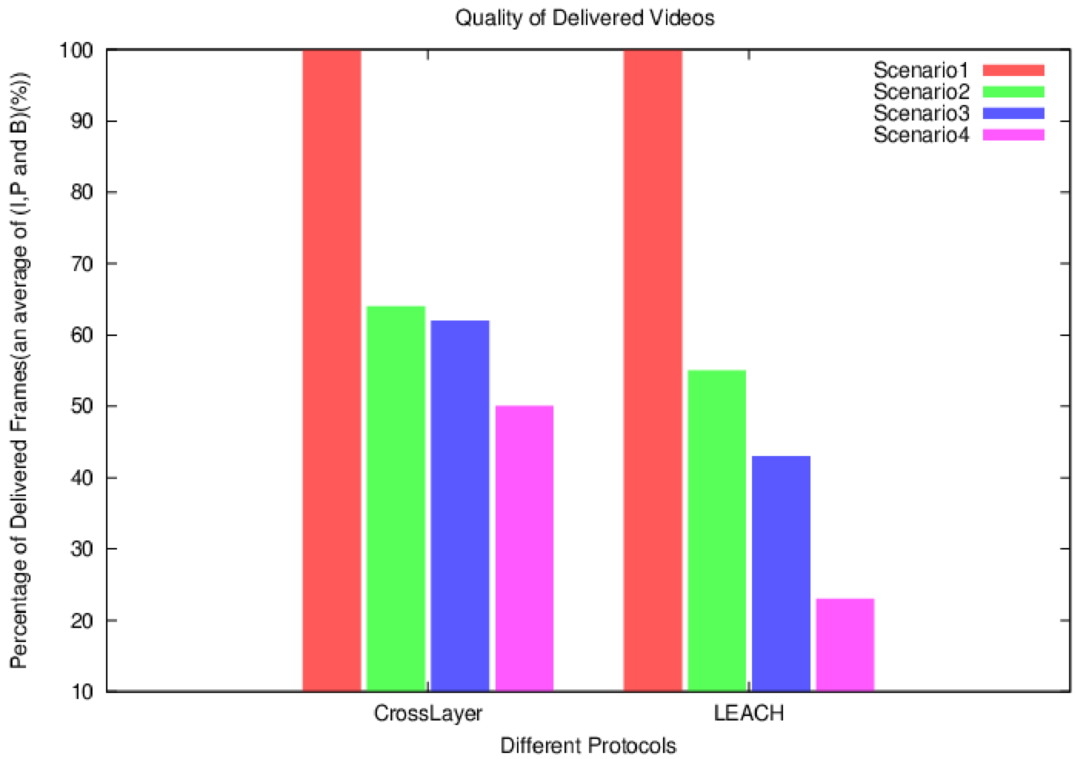

Figure 9: Quality of the transmitted videos based on an average of the delivered frames

However, as shown in Figures 9 and 10, the cross layer based protocol performs better than LEACH protocol in term of delivering multimedia from source nodes to a sink, where data cannot be delivered from source node to a sink using a single hop communication (second and third scenarios). This performance is due to the fact that proposed cross layer based protocol uses multi hops, with a cross layer solution to select reliable routes based on the network conditions, i.e., RSSI, remaining energy and number of hops. This improvement decreases packets loss and increases the quality of the transmitted videos. On the other hand, CHs using LEACH protocol cannot deliver data representing the detected events to a sink with acceptable rates, as shown in the same figures. This is because sink is not in the transmission range of such CHs and LEACH protocol does not consider cross layer information to select reliable routes using multi hop communication. CHs using LEACH protocol consider only a single hop communication and so makes LEACH unreliable routing protocol for large WVSNs.

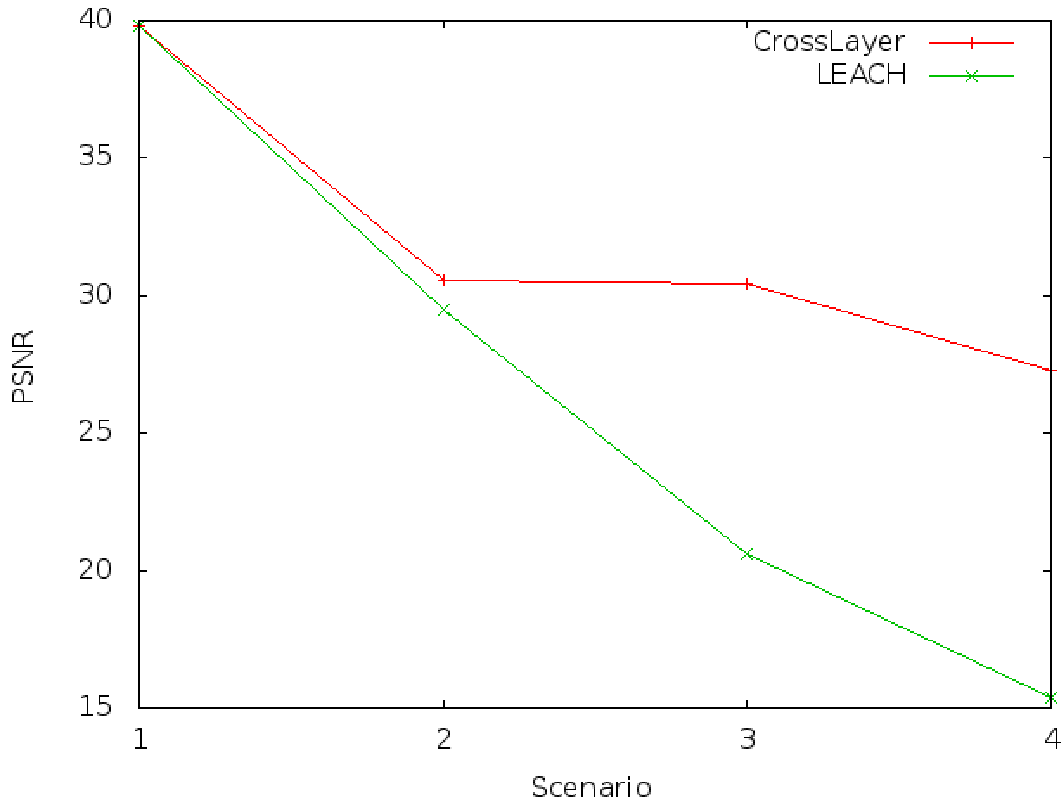

Figure 10: Quality of the transmitted videos based on PSNR metric

A very large and complex scenario is considered (fourth scenario) to measure both protocols where huge number of nodes are deployed in large networks and as shown in the same figures, the cross layer based protocol can still deliver data to a sink. This implies that the cross layer based protocol offers a good performance in term of the quality of the delivered videos based on PSNR and delivered frames results shown in Figures 9 and 10 for all scenarios. However, LEACH protocol delivers videos with a bad quality based on the results shown in the same figures, where large scenarios are considered (second, third and fourth scenarios). The reasons behind this conclusion are described above.

6.3.2 Lifetime of the Network

Figure 11 shows lifetime of the network using the proposed cross layer based protocol and LEACH protocol for the proposed application, considering different scenarios. As shown in Figure 11, the proposed cross layer based protocol extends the life time of network compared to LEACH in all simulated scenarios. The reasons for this are the following: (i) CHs in the proposed cross layer based protocol are selected based on the remaining energy and then the probability of nodes dying in their early stages is low. However, in LEACH protocol CHs are selected based only on randomly selected number between 0 and 1 as shown in [14]. (ii) The CHs in LEACH protocol use higher transmission power (i.e., 0 dB, as shown in Table 1) to deliver videos toward a sink in all scenarios given in this paper, using single hop communication. However, cross layer based protocol lets CHs use low power transmission (i.e., -10 dB) when delivering videos toward a sink using both multi hops and single hop communication and then the lifetime of the network is extended. Based on this and as shown in Figure 11, a WSN for all given scenarios using the proposed cross layer based protocol can be survived between 18 and 33 days, compared to LEACH protocol where WSN can be alive between 4 and 26 days.

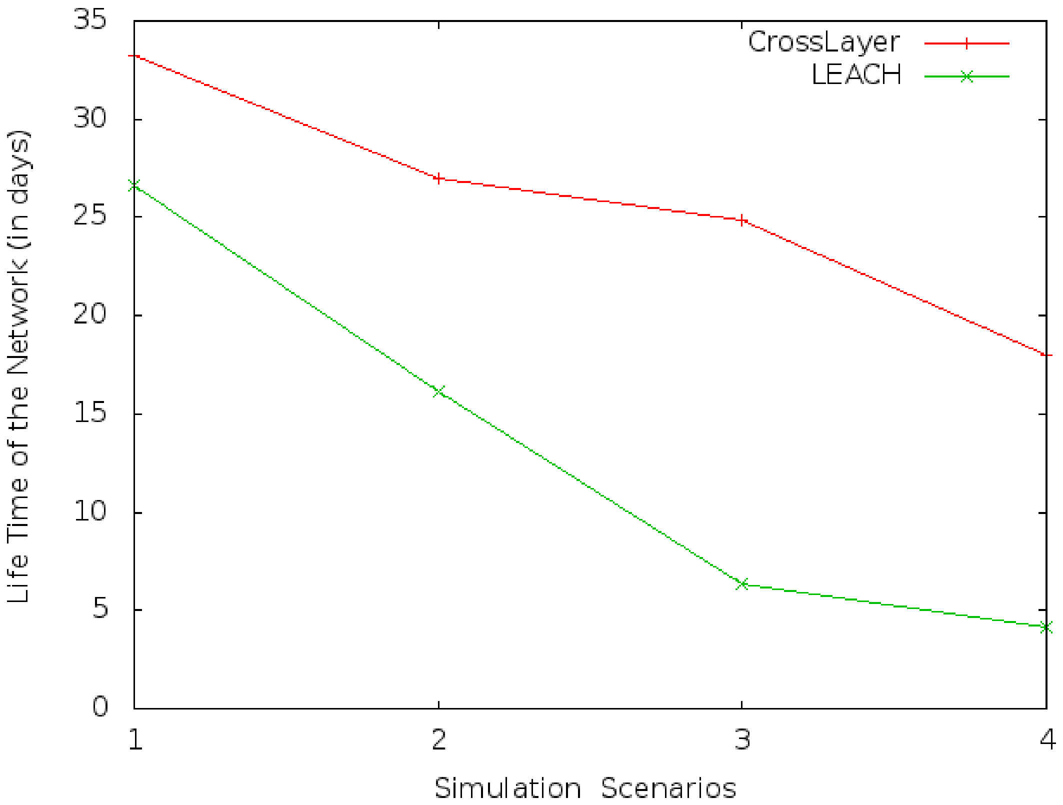

Figure 11: Lifetime of the network (in days)

6.3.3 Delay for the Delivered Videos

Multimedia clips from source nodes for all scenarios using both LEACH and cross layer based protocols are delivered within a very short delay as shown in Figure 12. Based on this result, the proposed cross layer based protocol does not perform better than LEACH in term of delay for delivering data from source nodes to a sink. However, this performance is good enough for the proposed application so that the right actions can be taken when expected event are occurred in the network. This performance is because LEACH uses only a single hop communication for delivering data and then delay is decreased, compared to the proposed cross layer protocol where some delay is produced because of multi-hop communications between source nodes and a sink.

All detected and alarmed events from different parts of the network regarding all given scenarios using both protocols are delivered within the first minute as shown in Figure 12. This performance using both protocols is due to: (i) only cluster heads are involved for routing and forwarding data toward a sink in which reduces the routing complexity in large WVSNs and then reduces delay for delivering data. (ii) Cluster heads capabilities for aggregating and reducing redundant copies of data at the intermediate nodes in the network thus delay is optimized.

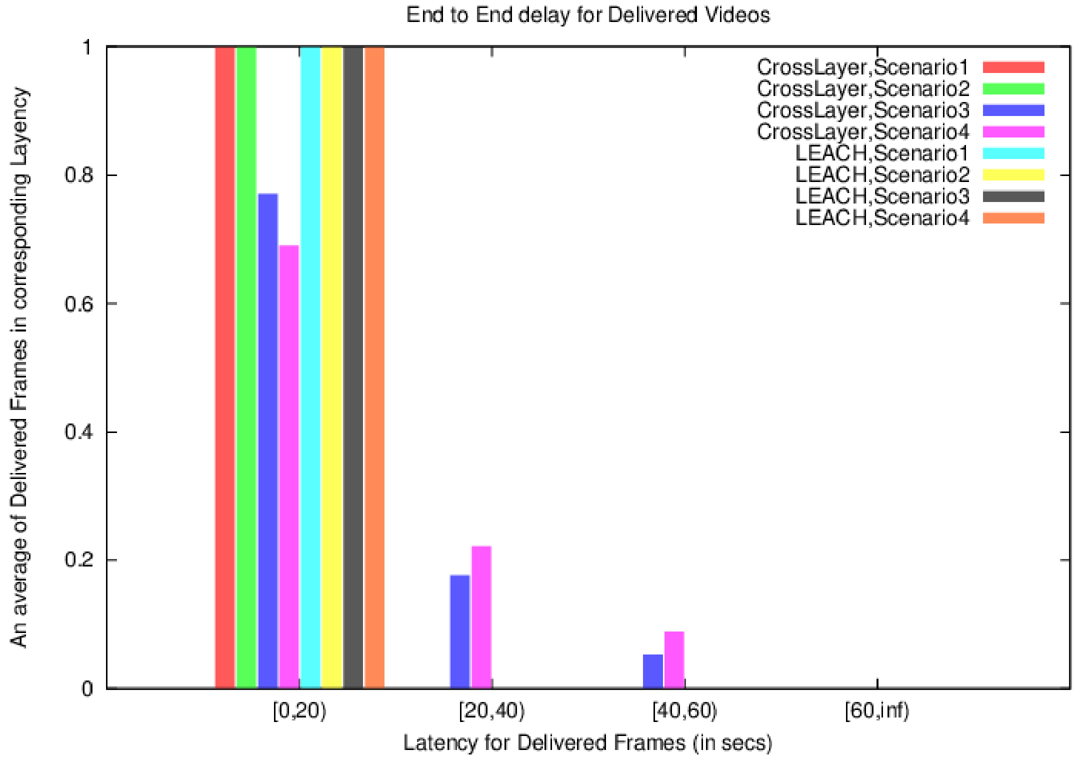

Figure 12: Delay for delivered videos

7 Conclusion

A cross layer based protocol for multimedia related application using WVSNs, where different events need to be captured from the target environment and sent to a sink, has been described in this paper. The cross layer based protocol has been simulated and compared to LEACH using different scenarios and results were presented in this paper. Security applications oriented toward critical infrastructures and disaster relief are very important applications that many countries have identified as critical in the near future. This paper aims to design a cross layer based protocol to provide the required quality of services for security related application using wireless video sensor networks. Nodes in the proposed application must be use alive for a long time, otherwise, application may not fulfil its purpose. In additional, quality of the delivered video need to be clear enough so that the proper action can be undertaken in real time. Based on these requirements, energy saving, delay and reliability for the delivered data are crucial for the application given in this paper. Simulation results show that the proposed cross layer based protocol can extend the lifetime of the network, by distributing energy usage between nodes. The delay and quality of the transmitted videos can be optimized by the proposing the cross layer information based on the network conditions when delivering multimedia over multi-hop communication. The cross layer based protocol could be enhanced to improve video transmissions by designing some video encoding related techniques such as Scalable Video Coding (SVC) to improve the quality of the delivered videos.

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