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On the Use of Passive Clustering in Wireless Video Sensor Networks

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Abstract:
Wireless Video Sensor Networks are foreseen to be of a paramount importance in realizing a wide spectrum of applications, mainly surveillance, target tracking and environment monitoring. In this paper, we propose a combination of an improved clustering algorithm and directed diffusion, a well-known data-centric routing paradigm in sensor networks. On the one hand, clustering allows to save bandwidth required by rich and intensive data of video applications. On the other hand, the network lifetime is prolonged by implementing an energy-aware load balancing feature through modifying passive clustering rules for building/maintaining its topology. We performed extensive computer simulations and show in this paper that our solution outperforms original directed diffusion as well as when it is combined with passive clustering with energy considerations but without load-balancing.

Keywords: Wireless Video Sensor Networks; routing; passive clustering; energy efficiency; load balancing; network lifetime.

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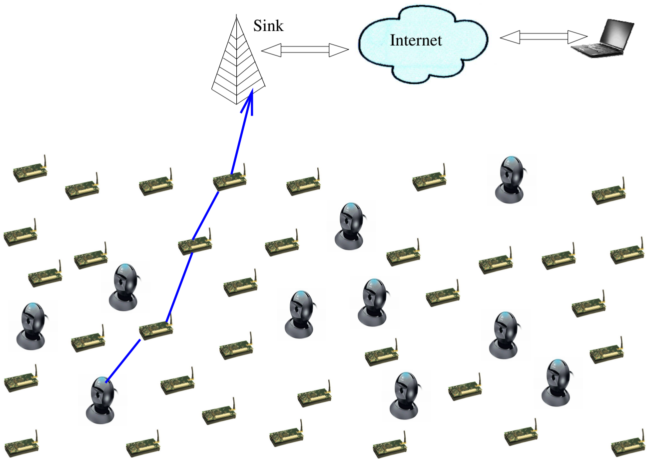


Figure 1 Typical Wireless Video Sensor Network

1 Introduction

Recent technological advances have led to the emergence of small low-power devices that integrate sensors with on-board processing and wireless communication capabilities. Pervasive networks of such sensors open new vistas for a wide spectrum of applications [Akyildiz et al., 2002]. Nowadays, these devices can be equipped with low-cost and low-power audio and visual modules allowing for fostering the development of Wireless Multimedia Sensor Networks (WMSN) [Akyildiz et al., 2007]. These latter provide significant benefit to many sensor networking applications such as surveillance, target tracking, environmental monitoring, and traffic management systems.

Wireless Video-based Sensor Networks (WVSN) are particular instances of WMSN where the scalar WSN is strengthened by introducing the ability of retrieving richer information content through image/video sensors [Rahimi et al., 2005, chi Feng et al., 2005]. A WVSN can operate in an ad-hoc manner and hence does not require a network infrastructure adding a much higher level of flexibility and allowing a wider range of applications. Figure 1 depicts a typical WVSN architecture where video sensors are deployed at strategic positions with other non visual sensors. A central controller or a base station commonly referred to as the *sink* is responsible for requesting/analysing sensed data. All nodes collaborate to ensure a given application requirements. For instance, low-power scalar sensors only take part in relaying in addition to sensing environmental data. Sensors with higher capabilities could do more such as taking part in a distributed compression task in order to not overwhelm video sensors by all the tasks (capture, compression and transmission).

WVSN generate unique challenging problems and should be designed to satisfy limited resources while providing a good video quality. WVSN applications require large amount of data to be transmitted with high reporting rates which consume an order of magnitude of resources, such as storage, computation, bandwidth and especially energy. Although these issues are abundantly studied in WSN, research is still in the earlier stage in WVSN and few works are accomplished.

Protocols in sensor networks rely heavily on flooding to discover routes and deliver data. Directed Diffusion (DD) [Intanagonwiwat et al., 2003] is a well-know data-centric routing protocol that deals with lack of global addressing using flooding. This mechanism, although simple and effective, can be quite inefficient because of large amount of redundant messages. These latter consume scarce resources such as bandwidth and particularly energy, an important design issue in WSN. Hence energy efficient routing protocols are highly required motivating the proposition of many new routing protocols [Akkaya and Younis, 2005].

Hierarchical routing protocols based on clustering techniques have been proposed to achieve scalability and reduce the need for global coordination. Clustering is the method by which sensor nodes in a network organise themselves into groups according to specific requirements or metrics. Each group or cluster has a leader referred to as *clusterhead* (CH) with possible one or more nodes belonging to at least two clusters called *gateways* (GW) in addition to other ordinary member nodes. As opposed to a flat organisation, clustering techniques allow more scalability, less consumed energy and thus longer lifetime for the whole network. In fact, most of the sensing, data processing and communication activities can be restricted within clusters. Moreover, clustering allows data aggregation which reduces congestion and energy consumption and can provide load balancing if appropriately configured. Furthermore, they can be naturally combined with data-centric routing to make use of data aggregation techniques.

Passive clustering (PC) [Kwon and Gerla, 2002] is a way to perform on-demand clustering to eliminate control messages overhead. It does not use any explicit control messages to maintain clusters. Instead, it relies on control information piggybacked on outgoing data packets. In WSN, PC was combined with DD in [Handziski et al., 2004, Rangaswamy and Pung, 2002] mainly to achieve energy efficiency. To determine a routing path, DD makes use of flooding in its different phases namely: interest propagation and exploratory data sending. Therefore, the main idea of the combination is to save energy in the flooding phases by allowing only clusterheads and gateways to take part in these phases. Ordinary nodes are only allowed to send data messages in the data sending phase. In [Mamun-Or-Rashid et al., 2007], the selection of clusterheads and gateways is based on residual energy. They also proposed to apply a periodic sleep and awake among cluster members with necessary synchronisation among nodes.

All the previously cited works [Handziski et al., 2004, Rangaswamy and Pung, 2002, Mamun-Or-Rashid et al., 2007] concentrate traffic on a set of nodes performing flooding. We argue that this concentration can lead to a variance in energy consumption among sensor nodes and is able to cause rapid partition of the network. To overcome this problem, we propose in this paper to alternate flooding nodes role (clusterheads and gateways) among nodes depending on their level of battery. A node with more energy is more likely to become and keep the role of a clusterhead or gateway. In this way, a load-balancing among nodes for data dissemination is achieved with higher lifetime for the whole network. This is even more interesting in the context of WVSN where a big amount of data is to be handled.

Our changes applied on DD showed that our mechanism outperforms DD and its PC combination proposed in [Handziski et al., 2004] in terms of network lifetime and delivery ratio. We mainly studied the performances of video transmission over WSN using our approach and show how the video quality can be enhanced using a clustering algorithm along with DD. In the literature, there are some few research work trying to enhance DD so to be more suitable to video transmission but, to the best of our knowledge, none made use of passive clustering.

This paper is organised as follows. Related work is presented in Section 2. Section 3 gives details of our proposal, the Energy Level-based Passive Clustering (ELPC). Simulation results are presented in Section 4 before concluding.

2 Related Work

Despite the great potential held by WVSN applications, only few ones can be found in the literature. Some visual systems for WVSN were proposed in [Rahimi et al., 2005, chi Feng et al., 2005, M. et al., 2004, Kulkarni et al., 2005, Gerla and Xu, 2003]. [Kulkarni et al., 2005] described the design and implementation of SensEye, a multi-tier network of heterogeneous wireless nodes and cameras. The surveillance application consists of three tasks: object detection, recognition and tracking. Multimedia transport over WSN is addressed in [Gerla and Xu, 2003] where a hierarchical network infrastructure is proposed to handle high bandwidth and low delay requirements of multimedia data by means of deploying a limited number of high capacity mobile nodes called swarms. [Aghdasi et al., 2008] proposed EQV-Architecture (Energy-efficient and high-Quality Video transmission Architecture) for video transmission in WSN. EQV consists of a prioritised video compression protocol in the application layer, a real time transport layer and a single-path routing protocol. Video packets are sent according to their priority and FEC are used in the link layer to achieve reliability. Another work [Klein and Klaue, 2009] addressed frequent topology changes through the use of Statistic-Based Routing (SBR).

In this work, we are interested in applying Passive Clustering (PC) techniques on Directed Diffusion (DD) while considering energy and whole network lifetime. In what follows, both DD and PC are summarised.

2.1 Directed Diffusion

Directed Diffusion (DD) [Intanagonwiwat et al., 2003] is the most popular data-centric routing protocol in the literature. Data-centric routing protocols are proposed to deal with the lack of a globally assigned identifiers scheme in WSN. The main idea is that data is routed based on its content rather than using routes based on unique identifiers of nodes in the sensor network. Directed Diffusion aims at diffusing data through sensor nodes by using a naming scheme for the data. It is query-based and suggests the use of attribute-value pairs for the data. In order to create a query, the sink sends an interest defined using a list of attribute-value pairs such as name of objects, interval, duration, geographical area, etc.

The interest is broadcast by a sink through its neighbours. Each node receiving the interest caches it for later use. As soon as a sensor node detects an event that matches one of the interests in its cache, it calculates a gradient for each neighbour node that delivers the matching interest. Thus, the gradients are setup from sensors to the sink. A gradient is a reply link to a neighbour from which the interest was received. Hence, by utilising interest and gradients, paths are established between sink and sources. The sink reinforces one or more paths by sending the same interest on the selected paths with a higher event rate. In addition to route discovery mechanisms, in-network processing may be employed to aggregate data to increase efficiency.

The on-demand nature of DD in constructing paths enables robustness and energy saving. Data caching and aggregation also make big benefit in terms of energy consumption and delay reduction. However, this latter feature is difficult to be applied to multimedia traffic. On the one hand, the matching process for data and queries might require some extra overhead at the sensors. On the other hand, only simple aggregation functions like averaging and thresholding are possible and are not applicable to multimedia flows that require more complex aggregation functions. The main drawback of DD, making it unsuitable to WMSN, is that it relies heavily on flooding to build and maintain paths. This is very expensive regarding required resources and can be more marked in dense networks. Finally, DD can not support time-sensitive traffic nor perform energy-balancing to increase network lifetime. This is due to the fact that it makes use of the same small set of paths in the routing phase which can lead to the exhaustion of nodes on these paths and cause network partition.

It is worth mentioning that there were some few work that addressed extending DD to fit multimedia applications in WSN. For instance, authors of [Li et al., 2008] proposed a multipath extension of DD where multiple routes are reinforced based on link quality and latency. The resulting algorithm is used for transmitting video traces generated by Multiple Description Coding [Goyal, 2001].

2.2 Hierarchical Routing and Passive Clustering

Hierarchical protocols [Heinzelman et al., 2000, Younis and Fahmy, 2004] save more energy compared to data-centric ones, are almost completely distributed and require no global knowledge of network. However, dynamic clustering brings extra overhead which may reduce the gain in energy consumption. Once again and like data-centric protocols, in-network processing at the cluster-heads is not practical for multimedia traffic especially in the presence of increased local communication.

In [Qin and Zimmermann, 2005] the authors proposed a novel communication protocol for studying the upper bounds on the lifetime of a video sensor network. They proposed to organise the sensors into clusters and a linear programming model is introduced for calculating a clusterhead rotation schedule. To verify the performance of the approach, the proposed scheme was compared to other clustering algorithms in sensor networks. Simulation results showed that this solution can extend the lifetime of a sensor network up to five times over that of existing approaches when the scale of the network is not very large. The proposed cluster formation algorithm is centralised and performed at the base station or at special node which is not suitable for wireless sensor networks.

Passive clustering (PC) [Kwon and Gerla, 2002] is an *on demand* clustering algorithm. It constructs and maintains the cluster architecture based on outgoing data packets piggybacking *cluster related information.* Passive clustering eliminates setup latency and major control overhead of traditional clustering protocols by introducing two innovative mechanisms for the cluster formation: *"first Declaration wins"* rule and *"gateway selection heuristic"*. With the *"first Declaration wins"* rule, a node that first claims to be a clusterhead *rules* the rest of nodes in its clustered area. The *"gateway selection heuristic"* provides a procedure to elect the minimal number of gateways.

The algorithm defines several states in which a node can be. At cold start, all nodes are in the initial state. Nodes can keep internal states such as *clusterhead-ready* or *gateway-ready* to express their readiness to be respectively a clusterhead or gateway. A candidate node finalises its role of a clusterhead (CH), a gateway (Full-GW or Dist-GW) or an ordinary node. Additional fields suggested by PC in the message header of each packet are :

- *id* : the identity of the originator of this message,
- *state* : this packet sender status in the network,
- $CH1$ and $CH2$: one (or both of them) is (are) used by a gateway to announce its clusterhead(s) id(s),

The reactive nature of PC motivated its combination with on demand routing protocols. Originally, PC was applied to reactive unicast (AODV [C. Perkins, 1999], DSR [Johnson et al., 2001]) and multicast (ODMRP [Lee et al., 2000]) routing protocols. The major overhead in these routing protocols is caused by the flooding of route queries. It was suggested to allow only non-ordinary nodes to rebroadcast query messages.

The PC algorithm presents some shortcomings that have been targeted by several works. In [Rangaswamy and Pung, 2002], the authors proposed to add alive packets to keep the cluster stability as it depends highly on the data packet traffic. Also, a sequence numbering to synchronise packets arriving from a source node is proposed. In fact, if packets containing different states arrive out-of-order at the destination (i.e., the sending node changed its state between transmission of multiple packets) then the destination node will be misled about the true state of the source node. In addition, unnecessary rebroadcasts are eliminated when the final destination of the message is a cluster member.

In WSN, the PC algorithm was proposed in combination with directed diffusion [Handziski et al., 2004] to mainly achieve energy efficiency. The main idea of the combination is to save energy in the flooding phases by allowing only clusterheads and gateways to participate in them. Ordinary nodes are only allowed to send data messages in the data sending phase. Under different network sizes and loads, the combination when compared to DD, showed better performances in terms of delivery ratio and average dissipated energy.

Motivated by the results shown in [Handziski et al., 2004] when applying the original PC along with directed diffusion paradigm other work have been proposed in order to achieve better performance of the combination. In [Mamun-Or-Rashid et al., 2007], the selection of clusterheads and gateways are done using a heuristic of residual energy and distance. By using residual energy the flooding nodes are chosen in an energy efficient manner. Distances are used to reduce the overlapping region and so the number of gateways. The solution proposed to apply a periodic sleep and awake among cluster members. This technique is similar to the one proposed in LEACH [Heinzelman et al., 2000] and requires a synchronisation process between nodes.

3 Energy Level-based Passive Clustering (ELPC)

The main idea in combining PC to DD is to reduce energy consumption by minimising flooding. As this process is known to be very costly, the energy expenditure of the flooding nodes will be much higher than those of ordinary nodes. This will cause a variance in the power amounts of the nodes in the network and by that a fast partitioning of the network. This is the case of all previously cited works where there is no load-balancing feature when combining PC to DD. In fact, topology construction in PC is done according to the lowest ID. The drawback of doing so is its bias towards

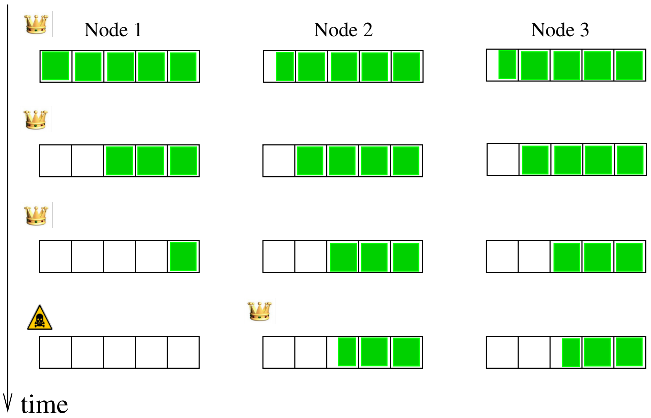


Figure 2 PC without load-balancing

nodes with smaller IDs leading to their battery drainage. Assume that three nodes 1, 2 and 3 (with same initial amount of energy) are contending to be a flooding node as shown in Figure 2. If we use PC algorithm, node 1 will be selected to be a CH since it has the smallest ID. Even if we consider energy as done in [Mamun-Or-Rashid et al., 2007], a CH will keep its role until it exhausts its whole energy.

In this work we propose ELPC (Energy Level Passive Clustering) to achieve energy efficiency in terms of network lifetime, not only in terms of energy consumption. This is done through alternating flooding nodes role (clusterheads and gateways) among nodes depending on their energy. The aim of doing so is to have the same amount of energy at all the nodes at a given time which increases substantially the whole network lifetime.

In ELPC, each node's battery is split into levels. One can make a correspondence between different energy levels of a node and virtual sub-batteries it consumed sequentially. The energy level (l) of a node can be computed using :

$$l = \left\lceil L \ \frac{E_r}{E_i} \right\rceil \tag{1}$$

where E_r is the remaining energy, E_i is the initial one and L is the suggested number of levels. For instance, if the number of levels is equal to 5, a node with only the half of its battery will have an energy level of 3.

We introduce the notion of *candidature* to be a clusterhead or a gateway by defining the *network energy level (nel)* parameter. A node is not allowed to declare itself as a clusterhead (or a gateway) if its energy level is lower than this parameter. A clusterhead (or a gateway) can keep its role as long as its energy level is higher than the *nel*. Otherwise, it gives up its role and passes to the *initial* or *ordinary* state according to whether it knows or not a clusterhead in its vicinity.

Finding a meaningful value for the network energy level is non-trivial. It depends on the energy level of the network nodes and can be viewed as the minimum level of energy necessary for a node to be a clusterhead or a gateway. We suggest to take an initial value that corresponds to the half of the battery charge. This value is decreased locally each time the condition to be a clusterhead is not satisfied. The local network energy level is then propagated within outgoing packets header. The local *nel* value is updated each time a node receives a smaller *nel* value.

l	nel	id	state	CH1	CH2	give–up

Figure 3 ELPC Packet header

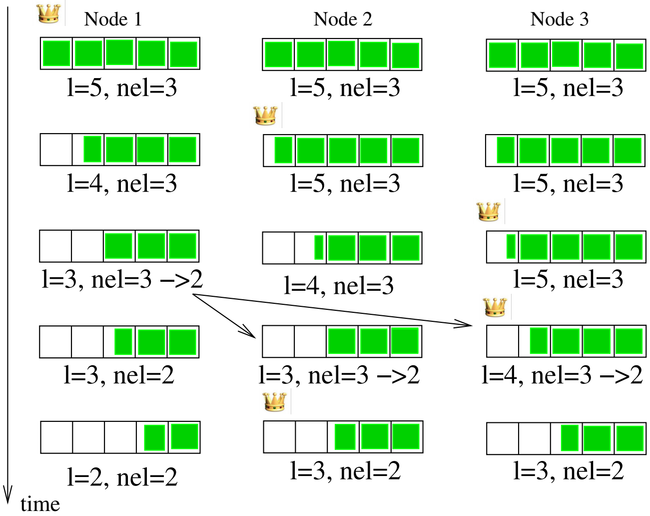


Figure 4 ELPC and load-balancing feature

We use the same states as suggested in [Kwon and Gerla, 2002] where a node is initially at the *initial* state. Nodes form and maintain the clustering topology by changing their internal and external states based on incoming and outgoing messages. When sending the next message, a node announces its external state which becomes visible in the network. Algorithm 1 summaries how PC is modified to allow load-balancing feature depending on nodes energy levels.

In addition to the PC related fields, we add the following ones to the packet headers (Figure 3) :

- l, node's energy level
- *nel*, the network energy level
- *give-up*, as in [Handziski et al., 2004] is set when the node is a CH that gives-up its role. It is used to replace the *give-up* message proposed in [Kwon and Gerla, 2002]. In ELPC, this field is set when the energy level of a CH drops bellow the *nel*.

Figure 4 illustrates the same example of Figure 2 with ELPC applied. The number of levels is chosen to be five for all the three nodes and the *nel* is initially set to 3 corresponding to the half of battery charge. We can see that the clusterhead role is alternated between the three nodes depending on their energy levels. When two nodes have the same energy level, then the nodes' identities are used to solve conflict in declaring roles. At step 3, we can

Algorithm 1 ELPC

- $CH\_ list$ is the list of known clusterheads to this node,
- $GW\_ list$ is the list of known gateways to this node,
- $ORD\_ list$ is the list of known ordinary nodes to this node,
- $INIT\_ list$ is the list of known nodes to this node that are in initial state,
- $give\_ up$ if set, it indicates that this node wants to give-up its role,

Initialisation phase

```
$state \leftarrow initial$
loop
    wait for receiving/sending a message
end loop
```

Incoming message processing

```
$give\_up \leftarrow false$
if $msg.nel < nel$ then
    $nel$ ←msg.nel;
end if
if $msg.give - up$ then
    delete the node from lists and updates its state;
    return; {example: if the clusterhead has given-up its role,the node passes to the initial state}
end if
if msg.state == CH then
    if $state == CH$ then
        if $l < msg.level$ then
            $give\_up \leftarrow true$;
            add $CH$ to the $CH\_list$;
        else if $l == msg.level$ then
            Use nodes' identities to solve conflict (if any)
        else
            add the $CH$ to the $CH\_list$; check lists;
            return
        end if
    end if
else
    add the $CH$ to the $CH\_list$; check lists; recalculate my state;
end if
if $(msg.state == GW)$ then
    add the gateway to the corresponding list and update its state {the same principle is applied. Here the conflict takes place when the states are the same and the related $CH$ are also the same. The energy level is then used to solve it.}
end if
if $(state == initial)$ AND $(msg.state! = CH)$ then
    $state \leftarrow CH\_Ready$;
end if
```

Outgoing message processing

```
if $give\_up == true$ then
    $give\_up \leftarrow false$;
    if $CH\_list$ is not empty then
        $state \leftarrow Ordinary$;
    else
        $state \leftarrow initial$;
    end if
end if
if $state == CH\_Ready$ then
    if $l > nel$ then
        $state \leftarrow CH$;
    else
        decrease $nel$;
        if $CH\_list$ is empty then
            $state \leftarrow CH$;
        end if
    end if
end if
if $state == GW\_Ready$ then
    if $l > nel$ then
        $state \leftarrow GW$;
    else
        decrease $nel$;
        if $GW\_list$ is empty then
            $state \leftarrow GW$;
        end if
    end if
end if
if $(state == CH)$ OR $(state == GW)$ then
    if $l < nel$ then
        $give\_up \leftarrow true$;
        if $CH\_list$ is not empty then
            $state \leftarrow Ordinary$;
        else
            $state \leftarrow Initial$;
        end if{the same principle is applied if the node is a gateway. If the first condition is not satisfied the node declares itself as an ordinary node: $state \leftarrow Ordinary$}
    end if
end if
Update msg fields; send msg;
```

note that node 1 decreases its *nel* to 2 (since $l = nel$) and propagates this new value to its neighbours so all nodes can have same estimation of the network energy level. It is straightforward that using ELPC compared to PCDD (Figure 2), we enhance the network lifetime by allowing fair energy distribution among nodes.

Figure 5 shows the establishment of routing structures of directed diffusion when this latter is used in combination with ELPC. Initially, all nodes in the network are in the *initial* state. Nodes will use the first interest messages to establish the new topology as described in the algorithms. A possible topology is illustrated in Figure 5(a-b). After establishing the gradient (Figure 5(c)) and path reinforcement (Figure 5(d)), the source begins sending the sensed data. When the energy level falls under the network energy level at node A, it gives-up its role of clusterhead (Figure 5(d)). Thus, a new topology is established (Figure 5(e)). This is done using next circulating messages in the network (data messages, interests, exploratory data). The resulting passive clustering can be applied to any routing protocol in sensor networks as they mostly rely on flooding and particularly with DD. This not only reduces energy consumption as in [Handziski et al., 2004], it also increases the whole network survivability as it will be shown in section 4.

Before presenting the simulation results, we show using a simple formal method how ELPC allows longer lifetime than PCDD. A more accurate and developed formal method is beyond the scope of this paper. Consider a network region with one cluster and say $k, k \geq 1$ potential candidates to be a clusterhead. Let E_L be the amount of energy per level which we consider to be the same for all the region sensors. Let E_i be the available energy at a sensor i in the beginning of the session where $E_1 \leq E_2 \leq ... \leq E_{k-1} \leq E_k$. We call a *round* the time interval in which a given candidate is a clusterhead. Let P be the power dissipation of a sensor when it is a clusterhead.

In PCDD, the number of rounds is k since each candidate becomes a clusterhead once. Each round lasts E_i/P when sensor i is the clusterhead in this round. Given that a region lifetime is defined as the time until the first candidate dies, the PCDD lifetime corresponds to the duration of the first round. Since, it is the candidate with largest amount of energy (k) who is elected for the first round, then this region lifetime in PCDD can be given by :

$$\Lambda^{PCDD} = \frac{E_k}{P} \tag{2}$$

In ELPC, the number of rounds is $\sum_{i=1}^{k} E_i/E_L$ and each candidate (i) becomes a clusterhead E_i/E_L times. This is because each round consists in exhausting a level (E_L) of energy. It comes that each round lasts E_L/P. When the first clusterhead is died (the kth one with the largest amount of energy at the beginning of the session), it remains one level of energy for the $(k-1)$ other candidates and this region lifetime can be computed as follows :

$$\Lambda^{ELPC} = \frac{E_L}{P}(\sum_{i=1}^{k-1}(E_i/E_L - 1) + E_k/E_L)$$

Equivalently :

$$\Lambda^{ELPC} = \frac{1}{P}(\sum_{i=1}^{k} E_i - (k-1)E_L) \tag{3}$$

Note that $E_i = E_L$ when $L = 1$ and that :

$$\forall i = 1, k-1 : E_i \geq E_L$$

Then we can write the following :

$$\sum_{i=1}^{k-1} E_i \geq (k-1)E_l$$

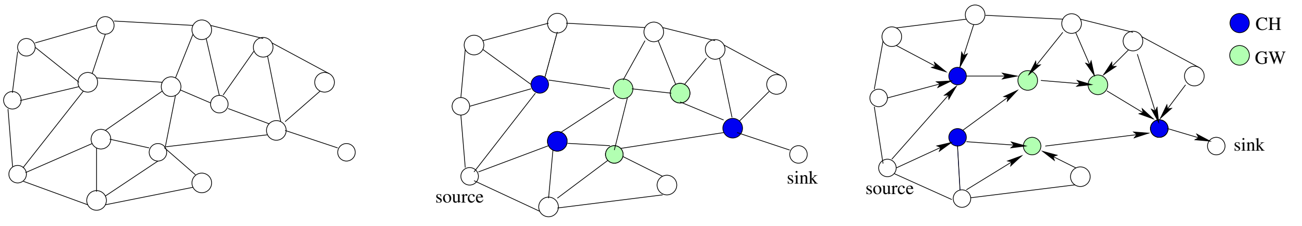
$$\sum_{i=1}^{k} E_i \geq E_k + (k-1)E_l$$

Dividing by P, it follows that $\Lambda^{ELPC} \geq \Lambda^{PCDD}$ and that $\Lambda^{ELPC} > \Lambda^{PCDD}$ when $L > 1$ and $k > 1$. This means that if we have only one level of energy ($L = 1$) or just one potential candidate to be a clusterhead ($k = 1$), ELPC behaves exactly like PCDD. To get better performances in ELPC, we need naturally to have more than one level of energy and more than one potential candidate so the network connectivity is ensured for longer time.

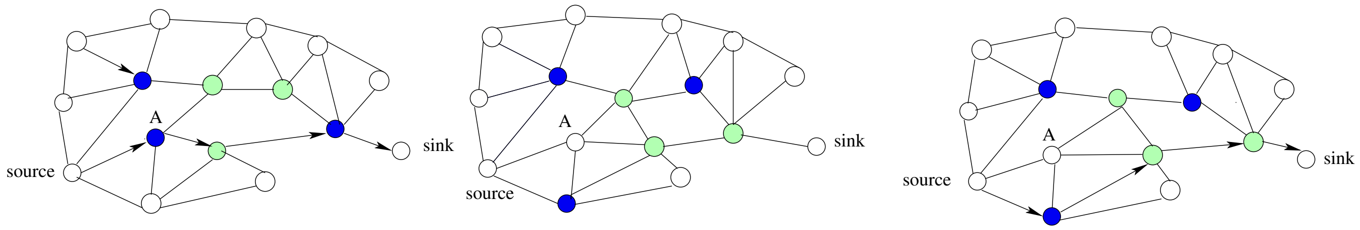
4 Simulation Results

We implemented our energy-level passive clustering (ELPC) using NS-2 [ns2] and compared it to the original directed diffusion (DD) and PCDD (DD combined to passive clustering with energy considerations but without load balancing feature as done in [Mamun-Or-Rashid et al., 2007]). We used the Two Phase Pull diffusion algorithm with its two flooding phases. The interest flooding is initiated by the sink and the data messages flooding is performed by the the sources upon event detection in the network. Additional fields in the message header are added as attributes to represent the node's energy level and the network energy level.

For all the experiments conducted in this paper, the sensors field is of 160 × 160 $m2$ with a varied number of nodes ranging from 100 to 500 nodes. We used the IEEE 802.11 and the two-ray propagation model. The radio propagation of each sensor node reaches up to 40 meters. We took the same amount of energy per level (5 J) at all nodes so the number of energy levels depends on the initial amount of energy at nodes. Results are averaged over 20 randomly generated topologies.



a. Initial Topology: all the nodes are in Initial State.
b. Topolog after roles assignment
c. Gradient establishement



d. Path reinforcement
e. A new topology: A gives−up its CH role
f. Path reinforcement in the new topology

Figure 5 ELPC illustrated

We performed both sufficient and insufficient energy scenarios. In the first set, nodes have sufficient amount of energy to terminate the simulation (the source is able to send all the video clip considered). This allows us to mainly assess the average dissipated energy per correctly received information. In the second set of simulations the amount of energy at nodes is chosen so it is smaller than the minimum required energy in the three protocols. This allows us to assess the network lifetime in seconds. This latter is obtained using the time at which the sink receives the last data packet from the video source.

To evaluate the quality of a video transmitted over our WVSN, One video sensor is assumed to capture and transmit a video sequence. We selected one of the standard video sequences used by a variety of video encoding and transmission studies called "*Hall Monitor*". It lasts 10 seconds and consists of 300 frames in CIF resolution (352×288). The video sequence is encoded in MPEG4 using ffmpeg [ffm] with a target bit rate of $128Kbps$ and a Group of Pictures (GOP) of 30. Only I (intra) and P (predicted) frames were generated in video traces using the open source EvalVid set of tools [Klaue et al., 2003]. The reference (or the sent video) PSNR (Peak Signal to Noise Ratio) obtained is 29.70 dB.

We considered the evaluation, in terms of PSNR, of the received video quality to show the benefit of passive clustering to video applications in WSN. The PSNR between the sent (s) and the received (r), possibly distorted video sequence is computed using :

$$PSNR(s,r) = 20log\frac{V_{peak}}{MSE(s,r)} \tag{4}$$

MSE is the mean square error which is the average of the square of the errors (pixel differences) of the two images and V_{peak} is the maximum possible pixel value.

We conducted experiments in order to empirically find the optimal data packet size for a good trade-off between energy efficiency and video quality. We considered a 200-node network and vary the data packet size from 32 to 2048 bytes. We obtained similar results for both insufficient and sufficient energy scenarios. We chose to present here only curves related to insufficient energy experiments. Figure 6 plots the loss ratio for the three simulated protocols (DD, PCDD and ELPC) as a function of data packets size. It is seen that the performances show a drop for packets size around 128 bytes. This behaviour can be attributed to the higher packet drops caused mainly by collisions for smaller packet sizes as bigger number of packets are to be sent. Even if the number of lost packets is smaller for large packet sizes, these losses affect considerably the loss ratio as the number of packets to be sent is smaller.

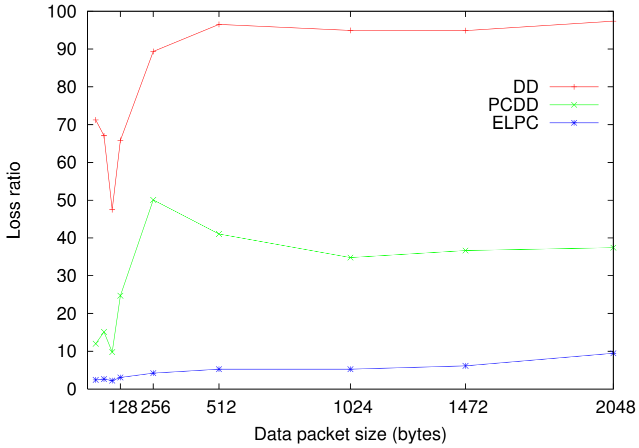


Figure 6 Loss ratio

Our experiments show that the empirical optimal data packet size is 128 bytes which corresponds to the smallest loss ratio. This value is confirmed in video quality measurements and network lifetime shown in Figures 7 and 8 respectively. We can see that the maximum PSNR and lifetime for all the three protocols

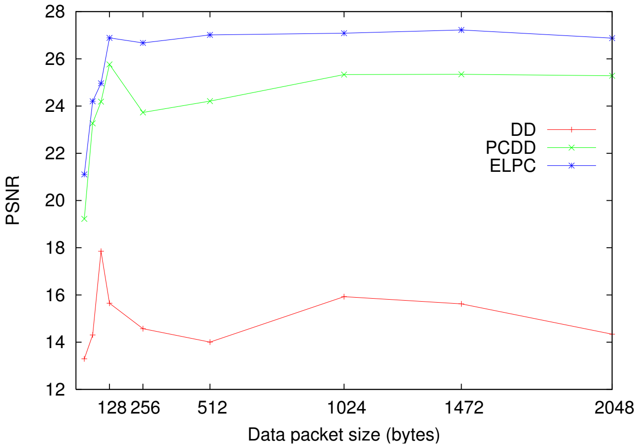


Figure 7 Video quality (PSNR)

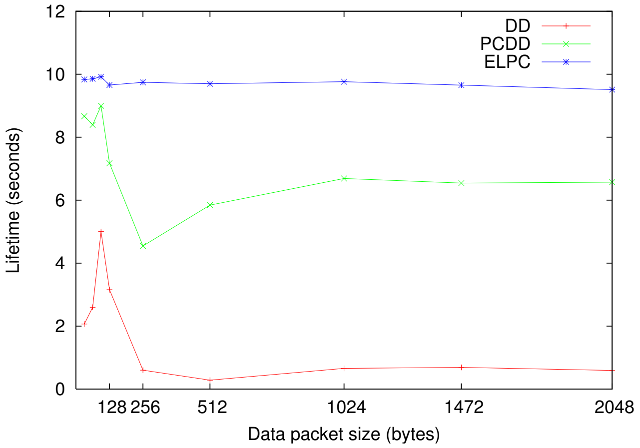


Figure 8 Network lifetime

are obtained for data packets of 128 bytes. These experiments confirm in someway the results presented in [Sankarasubramaniam et al., 2003] where it is shown that for a given bit error probability, energy efficiency decreases when packet size exceeds a threshold which is nearly 100 Bytes. At this stage, it is worth mentioning that ELPC presents the best performances regardless the data packet size used.

In all what follows, we will use data packet size of 128 bytes. In subsequent simulations, the video clip is sent twice. This is done in order to get more insight into both the transient and steady phases of passive clustering in PCDD and ELPC. Each simulation runs until network partition (no way to reach the sink from the video source) or all the data packets composing the two clips are received by the sink. We start by giving the overall performances and then those related to the first and second clip periods.

4.1 Overall Performances

We are interested here in overall performances related to the entire simulation time from sending the first packet of the first clip until the last packet of the second clip. Figure 9 shows the energy gain obtained in PCDD and ELPC with respect to DD with sufficient energy. Passive clustering allows energy saving in both ELPC and PCDD where they at most consume 45% of what DD consumes for 100-node network. When increasing the network size, the gain is much improved mainly using ELPC (more than 85% of energy is saved compared to DD for 500 nodes). This is because in ELPC more data packets are delivered than in PCDD as will be shown later on.

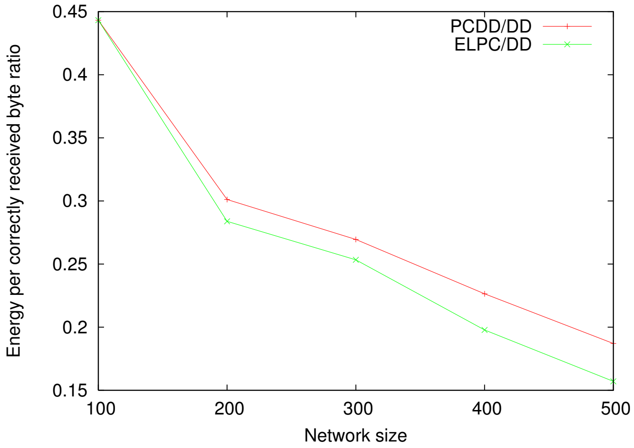


Figure 9 Energy ratio per correctly received byte (sufficient energy)

The improvement is mainly due to the fact that clustering reduces the number of floods in the network and thus nodes will consume smaller amount of energy. This helps in extending network lifetime. In ELPC, an alternation of the roles is achieved. Clusterheads or gateways give up their roles when other nodes with higher energy levels are in conflict with them or when their energy level is lower than the network energy level (nel). This encourages other nodes to declare themselves for these roles and, by that, leads to an increasing in the nodes lifetime. As a consequence, the lifetime of the whole network is extended. The nodes of the network are then able to forward more data, which, permits to the sink to receive a higher number of events.

Prolonging the network lifetime is our primary goal when proposing ELPC. We conduct experiments with nodes assigned insufficient energy to capture network lifetime. We use as a lifetime metric, the duration of the video received by the sink. Figure 10 plots as the network size increases, the network lifetime for the three protocols with insufficient energy. The network lifetime slightly decreases with the number of nodes increasing since a larger number of nodes results in a higher number of floods and hence bigger amount of energy is consumed in the network. Our solution (ELPC), however, achieves better performances compared to the two others. In ELPC, almost the two clips are received and the network lifetime is estimated to be nearly 20 seconds, the two clips duration. However PCDD and DD best lifetime does not exceed 13 and 9 seconds respectively.

Regarding video quality, ELPC outperforms both DD and PCDD mainly for insufficient energy scenarios as shown in Figure 11. Video quality decreases with

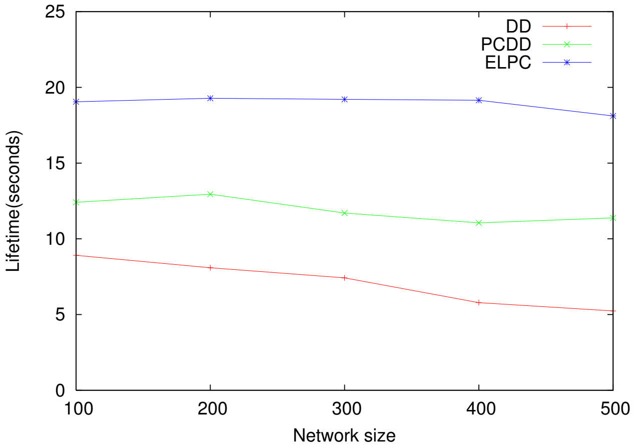


Figure 10 Lifetime with insufficient energy

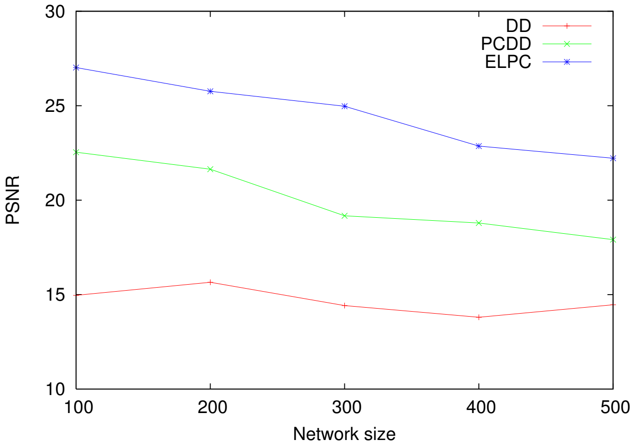


Figure 11 Overall PSNR with insufficient energy

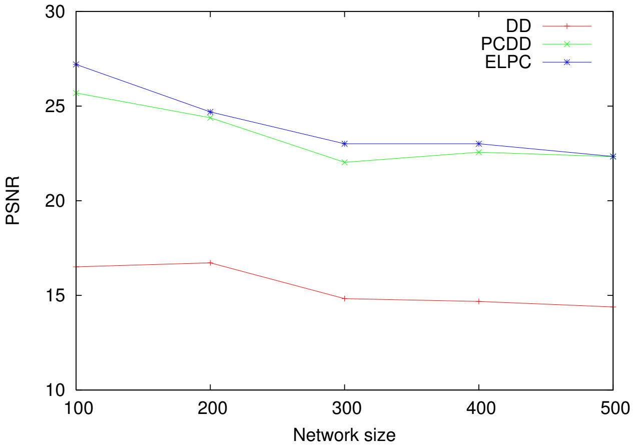


Figure 12 Overall PSNR with sufficient energy

the network size increasing since larger number of nodes results in a higher number of floods and hence bigger amount of losses which affect directly the quality of received video. For sufficient energy as shown by Figure 12, ELPC and PCDD presents nearly same performances. Enough energy does not allow distinguishing the two protocols.

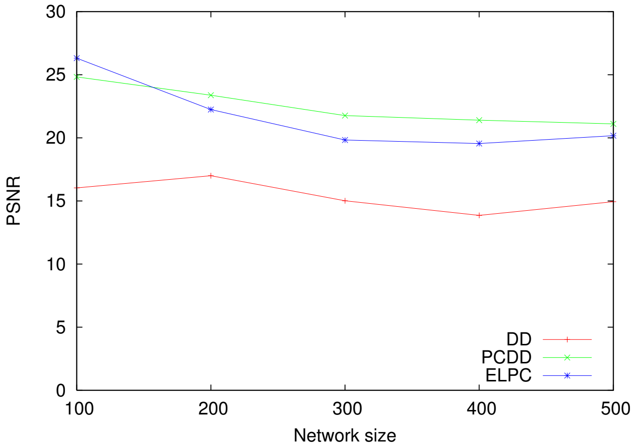


Figure 13 Video PSNR - First clip

4.2 First Clip Period

Here, we are interested in studying the transient period of the three protocols mainly PCDD and ELPC since clusters formation needs a given period of time to completely converge (the clustered topology is entirely built). It is worth saying that first clip related results (mainly for PCDD and ELPC) are nearly the same for both sufficient and insufficient energy scenarios since the amount of available energies are chosen (even in insufficient energy case) so at least a minimum number of the first clip frames are received by the sink.

Figure 13 shows the video mean PSNR as the network size increases. We can observe that ELPC and PCDD present relatively same performances. This is was to be expected since ELPC is likely to perform better when there is lack of energy in the network as will be shown in section 4.3. Figure 14, showing loss ratio of the three protocols as a function of the network size, confirms these results. We can see that ELPC and PCDD achieve roughly similar results which are clearly better than the ones given by DD. ELPC achieves better delivery ratio than PCDD in most cases however as already seen in Figure 13, it presents lower PSNR. This can be explained by the fact that in the performed set of experiments, there were more lost I-frames packets in ELPC. There is no way to distinguish I and P frames in all the three simulated protocols.

Figures 15 and 16 show the evolution of PSNR in per frame basis for one scenario with respectively 100 and 500 nodes for the three protocols as well as the reference PSNR (REF). This latter corresponds to the measured quality of the sent video and allows to consider only network effects on the video quality. It is clear that both PCDD and ELPC outperforms DD thanks to flooding reduction through clustering.

Clustering allows to achieve similar PSNR values as the reference PSNR except for the first 30 frames where ELPC and PCDD performances are as bad as those of DD. These 30 frames correspond exactly to the first transmitted GOP. Their bad quality can be explained by the presence of a transient period where

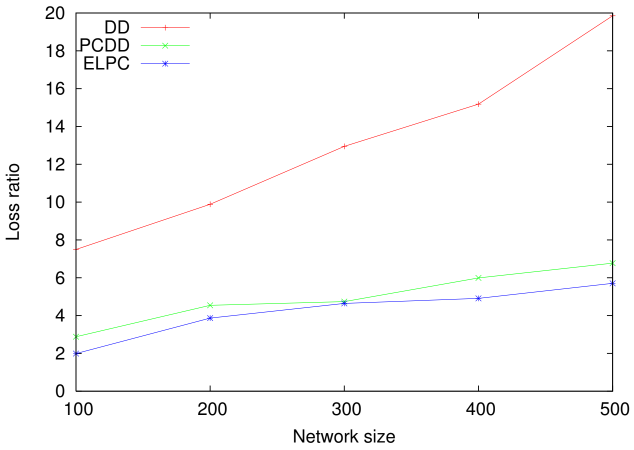


Figure 14 Loss ratio - First clip

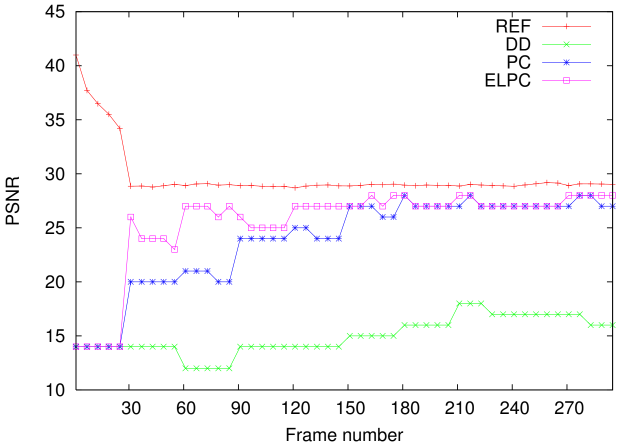


Figure 15 Mean PSNR per frame in the first clip video for 100-node network

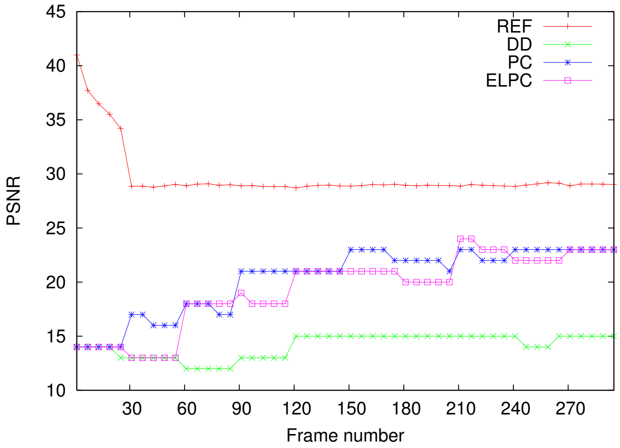


Figure 16 Mean PSNR per frame in the first clip video for 500-node network

the clusters are not formed yet in ELPC as it behaves as DD at the beginning. Many messages can be lost as the routing paths are not properly established. This took place because flooding nodes are not yet designed in the network.

The mean PSNR obtained with ELPC is of about 26.31 dB for 100-node network while it is of only 16.03 dB for DD. Note that the mean PSNR of the transmitted video is 29.7 dB. DD is unable to reach a PSNR greater than 18 dB which is very bad as can be observed in Figure 17. For a 500-node network, similar results are obtained when comparing the three protocols however with lower PSNR values due to scalability issues mainly for DD.

Figure 17 shows two sample images as sent (a) and received by the sink using DD (b), PC (c) and ELPC (d). Video quality enhancement of ELPC compared to DD is noteworthy. For instance, the best achieved quality in DD corresponds to the image in the left (14.1 dB) for which, we can note the bad quality especially compared to the one of ELPC (with a PSNR of 27.56 dB). This can be explained by losses caused by messages dropped due to congestion in the network as large number of flooding are performed according to DD conception.

4.3 Second Clip Period

In this section, we are mainly interested in comparing ELPC to PCDD to see how the former compared to the latter is able to enhance video quality mainly for insufficient energy scenarios. Figure 18 plots the mean PSNR obtained at the sink as function of the number of sensor nodes with sufficient energy. The first thing to note is that even with sufficient energy, DD performs very bad with a PSNR less than 19 dB. We chose to omit DD results since in many cases mainly for insufficient energy scenarios, only few frames are received from the second clip. This is why in subsequent plots, we only consider ELPC and PCDD.

As shown by Figures 18 and 19, ELPC allows better video quality in terms of mean PSNR with respect to

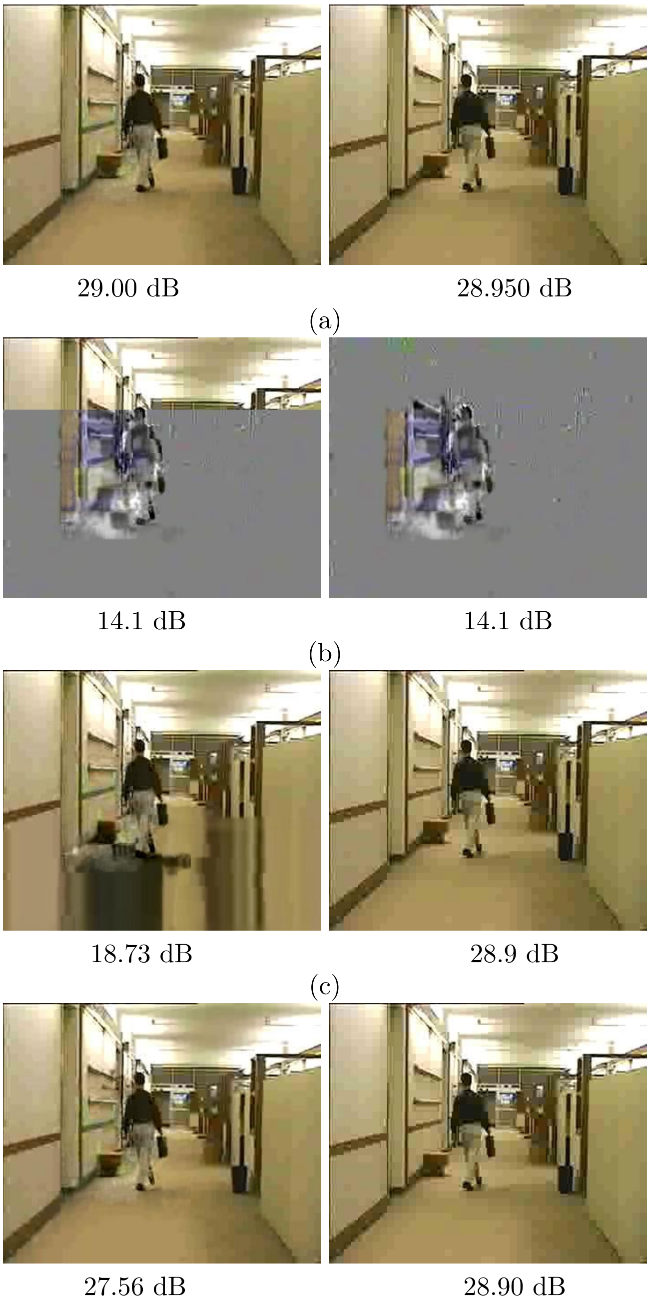


Figure 17 Sample of received frames (60 and 61) from the first clip : (a) Reference, (b) DD, (c) PC and (d) ELPC

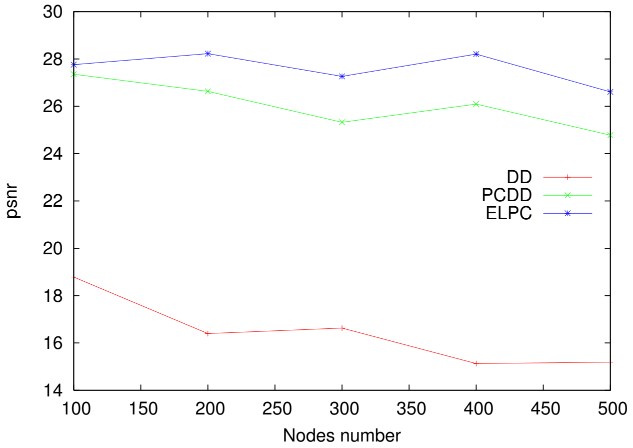


Figure 18 Mean PSNR with sufficient energy

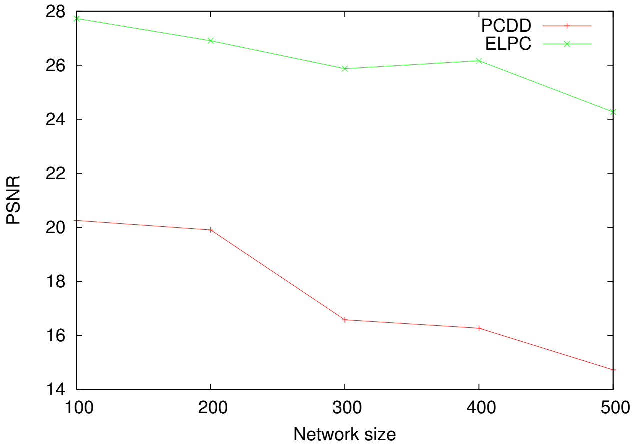


Figure 19 Mean PSNR with insufficient energy

PCDD regardless of initial amount of energy available at the sensor nodes. The difference is mainly observed in insufficient energy cases. Figure 19 shows that PCDD achieves at most a mean PSNR of 20.25 for a 100-node network while ELPC mean PSNR is 27.73 dB. Even if the network size is increased to reach 500 nodes, ELPC obtains a mean PSNR of 24.27 dB.

PSNR results of Figure 19 are confirmed by the loss ratio experienced by both protocols as depicted in Figure 20. In PCDD, the larger the network, the higher the loss rate since the traffic overheard is more important. This explains why the PSNR is worser when the network size increases. Losses are more important in PCDD because of higher number of nodes ran out of energy since no energy-aware load-balancing is performed. This leads to premature network partitioning and thus shorter lifetime as already shown by Figure 10.

Figure 21 plots the mean PSNR on a per-frame basis for a 300-node network with sufficient and insufficient energy. In both cases, ELPC outperforms PCDD especially for insufficient energy simulations where ELPC achieves a mean PSNR of 25.87 dB while PCDD a mean PSNR of only 16.57 dB suffering from higher loss rates. We can see that in ELPC, the frames

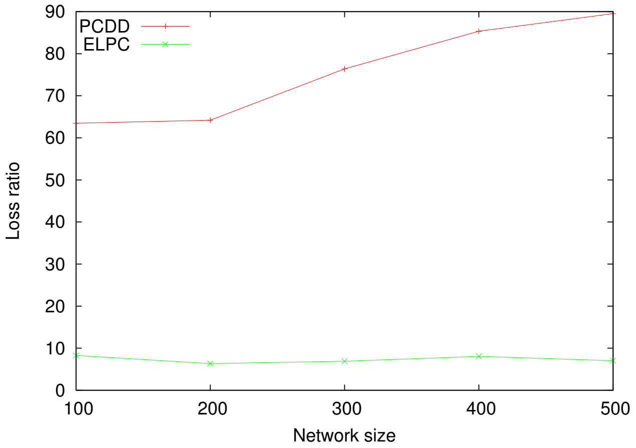


Figure 20 Loss ratio with insufficient energy

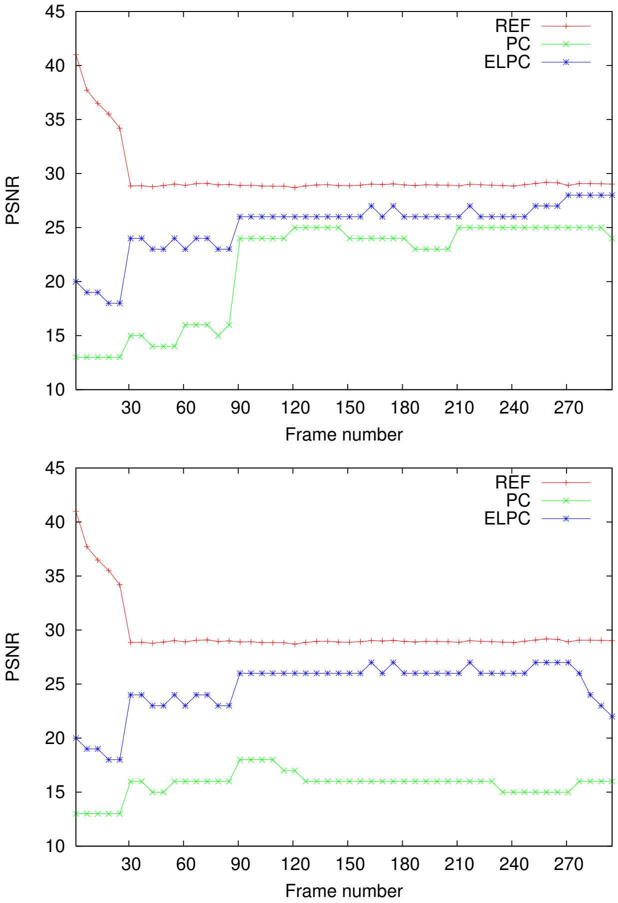
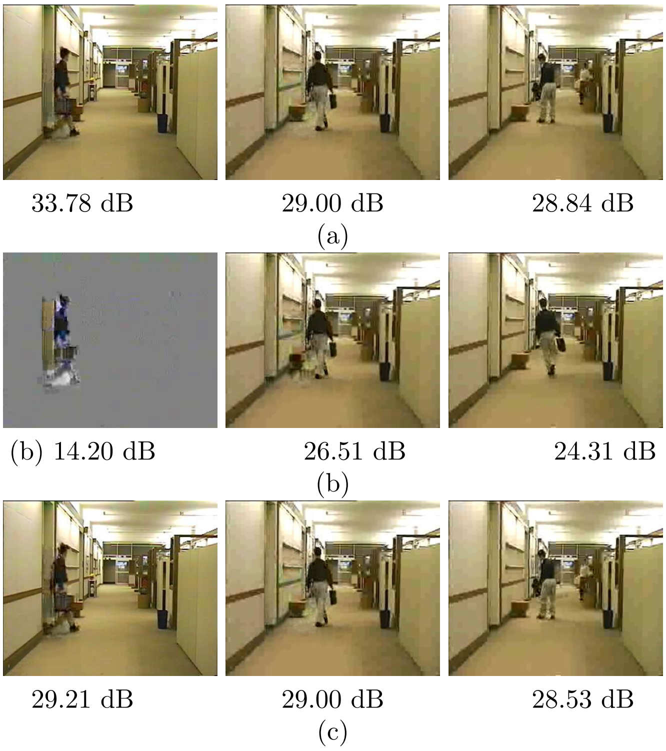


Figure 21 Mean PSNR per frame in the second clip video for a 300-node network with (a) sufficient and (b) insufficient energy

keep a fair PSNR until almost the end of the clip as the network lifetime is longer.



33.78 dB 29.00 dB 28.84 dB
(a)

(b) 14.20 dB 26.51 dB 24.31 dB
(b)

29.21 dB 29.00 dB 28.53 dB
(c)

Figure 22 Sample of received frames (30, 60 and 90) from the second clip with insufficient energy : (a) Reference, (b) PC and (c) ELPC

Figure 22 shows frames number 30, 60 and 90 as received by the sink in insufficient energy simulations in PCDD and ELPC as well as the reference ones (as sent from the source). The three frames correspond to the last frames of the three first GOPs. This allows assessing video quality using the worst frame in a GOP just before receiving a new I-frame that could increase considerably the observed PSNR. We can see that frames quality in ELPC is better than those obtained in PCDD and is of approximately the same quality of the reference frames. For instance, the frame 30 is received with only a PSNR of 14.20 dB with very bad quality in PCDD while it is received with a PSNR of 29.21 dB in ELPC. An other important observation is that frames 60 and 90 are nearly the same for PCDD. This means that very few data arrived at the sink from the third GOP. In the corresponding simulation scenario, the last received packet using PCDD corresponds to the 69th frame of the second clip. In the same simulation scenario, no frame from the second clip is received using DD.

5 Conclusion

In this paper, we proposed ELPC, a combination of a well known routing paradigm (DD) in sensor networks with an energy efficient cluster formation algorithm. This combination gives better performances in terms of network survivability and data delivery ratio when small amounts of energy are available. We were mainly interested in evaluating video transport in a WVSN using passive clustering. We conducted extensive simulations and showed that an approach like ELPC with energy-aware load balancing feature is very promising. ELPC allows longer network lifetime, lower loss rate and better video quality.

In the future, we plan to carry out deeper performance studies for different types of video and network conditions. Moreover, processing capacity of video sensors have to be considered. As a result, currently, we are working on encoding methods that consume less energy. We mainly expect to study the trade-off between processing requirements (mainly in terms of energy) and video quality. Priority schemes will also be considered since I-frames packets have to get distinguished from P-frames for instance.

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