Recent Advances and Challenges in Wireless Multimedia Sensor Networks

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1. Introduction

Wireless Sensor Networks (WSNs) Akyildiz et al. (2002), Zhao & Guibas (2009) are formed of spatially distributed autonomous sensor nodes (motes). They are deployed in an environment where they can be used to monitor environmental conditions in collaboration, and communicate with each other through the wireless links. Several applications that are used in different areas have been outlined in the literature, such as, medical applications for monitoring patients Shnayder et al. (2005), monitoring mission critical environments, e.g., volcanic eruptions Werner-Allen et al. (2005), monitoring the structural integrity of buildings/towers Ceriotti et al. (2009) and several other multimedia applications.

WSNs can be deployed in an environment that covers a large area with hundreds or thousands of motes that are able to sense physical values and send them to either one or a set of Base-Stations (BSs), or end-systems (including end-users).

WSN is part of a new network paradigm, called of Internet of Things (IoT) Atzori et al. (2010), that is becoming very popular in wireless communication systems. The principle of this paradigm is that objects or things interact and cooperate with each other to ensure ubiquitous communications. These objects or things might be Radio-Frequency IDentification (RFID) tags, WSNs, actuators, applications, mobile phones, among others.

In the context of future WSN/IoT systems, Wireless Multimedia Sensor Networks (WMSNs) Gurses & Akan (2005), Almalkawi et al. (2010) are attracting considerable attention from both academic and industrial research groups. WMSN provide a wide range of potential applications in both civilian and military areas, which require visual and audio information, such as a surveillance sensor network, environmental and industrial monitoring, intelligent traffic congestion control, health-care, and others multimedia digital entrainment, or green city applications. In all of these, the multimedia content has the potential to enhance the level of information collected, by for example, allowing multi-resolution views (making comparisons with the measurements of scalar data).

A typical multimedia mote (e.g., TelosB MEMSIC (2011c), MICAz MEMSIC (2011b) and IRIS MEMSIC (2011a)) is equipped with a radio transceiver or other wireless communication devices, a small microcontroller, an energy source (i.e., a battery), some scalar sensors (i.e., temperature, humidity, and others), and multimedia sensors (camera and/or audio). A mote might vary in size from that of a shoebox down to the size of a speck of dust. Due to recent technological advances, involving the rapid improvement and miniaturization of hardware, it has become possible to develop single and usually small devices equipped with an audio and video camera. An example of this device is the CMUcam Rowe et al. (2002), an embedded camera with a CIF Resolution (352 x 288) RGB color that can be interfaced with an IEEE 802.15.4 compliant radio transceiver (e.g., TelosB mote).

Basically, the WSN/WMSN stack consists of four layers (Physical, Link, Network, and Application), as shown in Figure 1. The lower layers (Physical and Link Layers) are defined by the IEEE 802.15.4 standard IEEE-TG15.4 (2006). However, no standard exists for the upper layers although they have some features which can be expected. The responsibilities of each layer outlined as follows: (i) the Physical layer is responsible for providing access techniques; (ii) the Link layer works on medium access control, (iii) the purpose of the Network layer is to route the data in a network, and finally, (iv) different types of applications can be built and used on the Application layer.

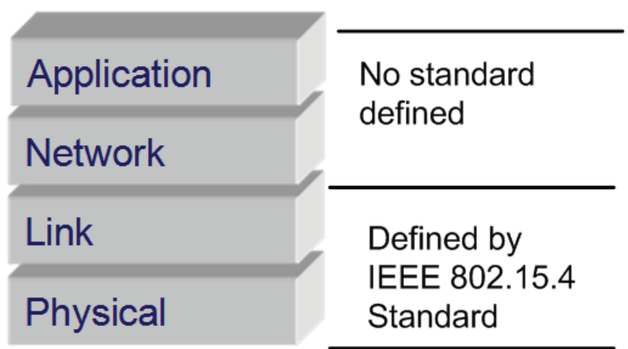

Fig. 1. WMSN Stack Layers

With regard to applications, multimedia sensing is expected to be wide-ranging. New WMSN network-based solutions must be specified, implemented and validated to support the requirements of multimedia applications in fixed and mobile sensor systems. Additionally, the sensor nodes have a limited power supply and are constrained in terms of bandwidth. All of these mentioned constraints impose a challenge in terms of the routing protocol in WMSN.

As mentioned earlier, the sensor nodes are usually deployed in a field that covers a large area and has hundreds or thousands of nodes. Thus, the nodes that are far away from the BS are unable to send their packets in a one-hop communication. Hence, it is necessary to use a multi-hop approach to provide a end-to-end communication.

From the perspective of the Network Layer, one of the main research problems is to ensure an efficient routing protocol with high-quality multimedia support for the WMSNs. This is hard to achieve because of the restrictions imposed by the WMSN features, which distinguish it from other wireless networks.

As presented in Al-Karaki & Kamal (2004), these new features are: (i) since the WSN has a large number of nodes and these are deployed in a wide area, it is difficult to have a global addressing system ; (ii) multiple sources send their data to the BS; (iii) the WSN has some restrictions with regard to energy, processing, and storage capacity; (iv) in some scenarios, the nodes are either static or mobile; (v) the location of a mote is important since the data collection is normally based on its location; and (vi), a WSN is usually composed of many motes and there is a high degree of probability that the collected data will have some redundancy.

This Chapter focuses on routing approaches for WMSNs and provides an overview of the most significant challenges and tendencies with regard to routing protocols for WMSNs, multimedia and network performance. Owing to the importance of the routing schemes and multimedia-awareness delivery in optimization operations, a particular attention will be given in this area. A number of different approaches to multimedia routing will be discussed to explain the nature of these challenges.

A use case will be discussed in this Chapter. The scenario selected is a multimedia-aware fire detection application in a rainforest area. Serious fires are common during the summer in the Amazon rainforest, and several research groups are attempting to monitor a fire alarm system. By using this system, it must be possible to collect information, such as temperature, humidity and multimedia data from the region and send it to the BS (or another end-system).

The BS will then forward the data to an end-system (e.g., desktop or mobile phone), where it will be analyzed and the possible occurrence of fire can be predicted. An integrated approach based on sensor data and physical models will be used to estimate the potential risks and hazards. This information can then be used to notify people and the local government can take appropriate measures to minimize the impact on the environment and save lives. A generic scenario of the use case is shown in Figure 2.

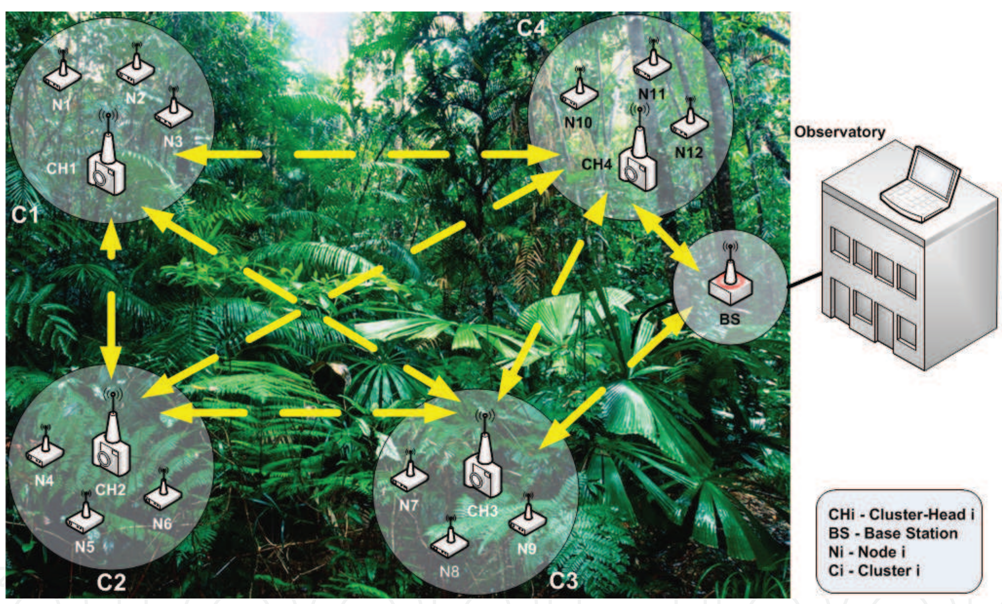

Fig. 2. A Recommended Generic Architecture for Fire Detection in the Rainforest Area

In the scenario outlined above, the nodes are deployed in a field (in this case in a rainforest) to carry out the sensing task, e.g., periodically collecting scalar data (temperature or humidity). The network is structured as follows: the architecture should have been designed in a hierarchical architecture, query-based, and with heterogeneous nodes (nodes with different capabilities).

The network architecture is hierarchical-based, as recommended for WMSNs in Akyildiz et al. (2007). Thus, the nodes are grouped in clusters, and a head node is assigned to each cluster, that is called the Cluster-Head (CH). In this scenario, the CH is a powerful mote that is equipped with a power supply and audio/video sensors. The main advantage of using a hierarchical-based architecture is its scalability and the fact that it is energy-efficient.

The nodes collect information about temperature and humidity, and send it to its CH which then forwards it to the BS by using multi-hop communications. The BS receives the data, and combines them with the aid of physical models, (e.g., the Angstrom index which is defined in Langholz & Schmidtmayer (1993)). The index is used to estimate the probability of a fire in a particular region.

The network can be classified as query-based, because after the BS detects the index value at a certain threshold, it will query/request multimedia data from the CH where the incident occurs. Thus, this application can be regarded as event-driven. The multimedia data is used to confirm the presence of fire, and then detect the impact of the disaster and assist the rescue operations.

The remainder of this Chapter is structured as follows. Section 2 provides a taxonomy of routing protocols, and addresses the main challenges and trends in designing a routing protocol for WMSN. Section 3 introduces the main features and drawbacks of routing protocols for WMSNs. Finally, Section 4 offers some final considerations on this Chapter.

2. Research directions and relevant issues in the design of routing protocols for WMSN

Owing to the small size of the sensor node, the WMSN nodes have limited resources, such as energy, bandwidth, memory, buffer size and processing capability. At the same time, the multimedia content (video stream, image or audio data) requires a high bandwidth, processing and storage capacity and this raises an additional challenge for the WMSNs. Additionally, the existing routing protocols for WSNs are not suitable for WMSNs. Thus, the design for routing protocols must take these constraints into consideration in order to overcome these drawbacks.

The multimedia content adds further restrictions to the design of routing protocols and makes it difficult to meet the application-specific Quality-of-Service (QoS) requirements and network conditions, e.g. ensuring that the end-to-end delay is within an acceptable range. Thus, providing an efficient routing scheme for the WMSNs, is a complex issue.

The following qualities are sought by most of the proposed routing protocols: (i) to be energy-efficient, and maximize the network lifetime; (ii) to be scalable, since the network must be composed of a large number of sensor nodes; (iii) to be fault-tolerant, due to the problem of sensor damage and battery exhaustion; and (iv) to have real-time, since in some applications the data has a real-time feature and has to take account of latency, throughput and delay. However, to the best of our knowledge, none of the proposed routing protocols for WMSN provides all of these features.

A routing protocol, usually aims to provide an efficient means of communication for a specific application, or similar applications. Thus, in designing the routing protocol, the researcher/developer must take into account important issues regarding the network structure, and which is the best approach for routing data.

In the following section, there is a taxonomy for routing protocols in WMSNs, which classifies the protocols according to the requirements of the network structure and protocol operation. Finally, there is a discussion of the main challenges and trends for the designing of a routing protocol.

2.1 A taxonomy for routing protocols

As mentioned earlier, WSN/WMSN has many features that distinguish it from other wireless or ad-hoc networks. Thus, several algorithms have been proposed to solve the problem of routing data in this network. These protocols must be developed by taking into account the characteristics of the sensor nodes and their applications, as well as the requirements of the network structure and architecture.

In Al-Karaki & Kamal (2004) there is a taxonomy for routing protocols in WSNs that can be extended to WMSNs, as shown Figure 3. According to this taxonomy, the protocols can be divided into two main groups: network structure and protocol operations; it is important to highlight that these groups are complementary. Depending on the network structure, the routing protocols can be classified into flat, hierarchical, or location-based networks. From the standpoint of the protocol operation, they can be classified into multipath, query, negotiation, QoS, or coherent-based protocols.

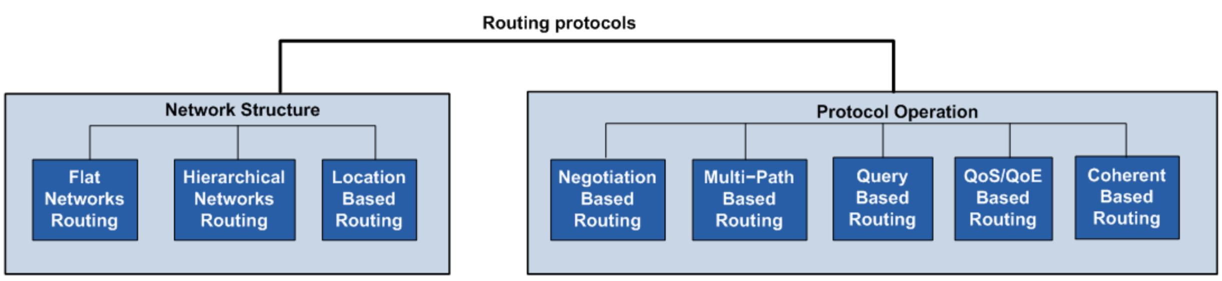

Fig. 3. Taxonomy for Routing Protocols

The way the routing protocol can be classified depends on how the source node finds routes to the destination node. In this context, the protocols are proactive, reactive or hybrid. In proactive protocols, all the paths are computed before they are really needed. In reactive protocols, the routes are computed on demand. Hybrid protocols use a combination of both proactive and reactive schemes. For static nodes, the best choice is to use a reactive protocol, since it implements a table-driven routing protocol and thus reduces energy consumption. In reactive protocols, the routes are computed on demand, which implies that a significant amount of energy is consumed in this task (route discovery and setup).

More detailed information will now be given about each of the categories of Figure 3. First, there is a classification based on the network structure of the routing protocols.

- **Flat networks:** all of the nodes have the same roles or functionalities, and collaborate with each other to carry out the sensing task, e.g., a sensor network deployed in an environment where all the nodes sense the temperature and humidity, so that they can send the information to the BS.
- **Hierarchical network:** the nodes are grouped in clusters and will play different roles in the network. The clusters are formed dynamically and a node in each cluster is elected as a leader; this node is called the Cluster-Head (CH). The main advantage of using this architecture is that it includes scalability and efficient communication issues. In this context, the nodes with higher energy are used to process and send information, while others with lower energy are used to carry out the sensing task.

- **Location network:** the node positions are used to route the data in a network. The relative location of the nodes can be estimated on the basis of the RSSI (Received Signal Strength Indicator) value of a received packet and by employing a radio propagation model. Alternatively, location information can also be obtained by communicating with a satellite, e.g., GPS (Global Positioning System).

Complementary, routing protocols can also be classified on the basis of the protocol operation, which varies depending on which approach is adopted. It should be underlined that some of the routing protocols may fall below one or more of the above routing categories. In the following section, there will be an examination of the detailed information of the network classification based on the protocol operation.

- **Multipath protocol:** to improve the performance of the system and ensure reliability, some protocols use multiple paths rather than a single path. Thus, alternate routes are established between a source and a destination node. Periodical messages are exchanged to maintain these alternate paths and these increase the network overhead.
- **Query protocol:** the protocol operation is based on request and reply queries through the network; these queries are usually described in either natural or high-level query languages. For example, a node sends a query to a specific node through the network, requesting sensing data (e.g., temperature), and the receiver replies to the sender with the data which matches the query.
- **Negotiation protocol:** the main purpose of this class of protocols is to eliminate duplicate information and prevent redundant data from beginning, by conducting a series of negotiation messages before the real data transmission. Additionally, communication decisions are taken based on available resources.
- **QoS/QoE protocol:** multimedia and mission-critical applications are sensitive to delay, jitter, loss, and other user- perceived metrics, such as blur and noise. This means that the QoS routing protocols must select routes that meet the quality level requirements of these applications. As a result, the use of QoS metrics is not enough to evaluate the quality of a video. Thus, recently a user perception scheme has been used to classify the multimedia content transmitted through the network. These user perception approaches are called Quality-of-Experience (QoE)-aware.
- **Coherent and non-coherent protocol:** this category of routing is focused on data processing techniques. The routing protocols can be classified as coherent and non-coherent data processing-based routing. If the nodes process the raw data before sending it, the routing protocol is classified as non-coherent data processing routing. Otherwise it is called coherent routing.

2.2 Challenges and trends for routing in WMSN

The main goal of a routing protocol is to carry out data communication while maximizing data delivery, extending the network lifetime, and preventing connectivity degradation. These goals can be achieved by employing data aggregation, energy management, and efficient control of path selection techniques. Additionally, there are restrictions of the nodes, and multimedia content which impose additional challenges. Thus, all these issues should be addressed at the time of the conception of a routing protocol for WMSN.

The performance of routing protocols for WMSN is affected by several complex factors. All of these must be overcome to provide an efficient communication system. In this subsection, there will be an examination of a list of issues which affects the performance of routing protocols, together with the way that they have been explored in the recent literature. Additionally, the use case examined in Section 1, will be used to show how these issues can be solved through the example of a multimedia-aware fire detection application in a rainforest area.

2.2.1 Data sensing and delivery model

This Section is related to the way that the nodes sense data (scalar or multimedia) and report to the CH/BS. The model can vary, depending on the nature of each kind of application. The delivery models can be classified as follows: continuous, event-driven, query-driven, and hybrid.

In a continuous model, the nodes are continually collecting data and transmitting it to CH/BS. This model is suitable for applications that require periodic sensing data. The event-driven and query-driven models are similar, in so far as the data are transmitted after an event occurs or when a BS requests a query. In some applications a hybrid model is employed, which is a combination of the previously used schemes.

- **Challenges:** the data sensing and delivery model affect the performance of the routing protocols. Especially with regard to energy consumption and route changes, i.e. if a node is continually capturing a video content and sending it to a CH/BS, the node in question will consume more energy. Thus, it reduces its own lifetime and, consequently that of the whole system as well. Depending on the type of the routing protocol, the data transmission will continually cause a route change. A similar kind of behavior occurs with scalar data transmissions.
- **Trends:** one of the possible means of tackling this problem is to consider employing an event-driven or query-driven sensing and delivery model. By using one of these techniques, the protocol will reduce the amount of transmitted data and will improve the network lifetime. The reason for this is that the data are transmitted only when an event occurs or is requested.

  Returning to the use case, some nodes collect scalar data in order to detect or predict an event, in this case a fire. The multimedia content will only be sent when an event occurs.

  Other studies in the literature, use the same means of solving the problem, as shown by Kandris et al. (2011), and Czarlinska & Kundur (2008). In the works referred to, once the sensor nodes detect an event in a certain region, the node(s) that is nearest to the event captures the multimedia content and sends it to the sink.

2.2.2 Node deployment

This can be categorized as being either deterministic or randomized. In the case of the deterministic deployment, the nodes are deployed manually in an environment where data transmission is routed through pre-determined paths. In contrast, for random deployment, the motes create an ad-hoc infrastructure with random location.

The choice of deterministic or random deployment depends on the type of sensors employed, as well as the applications and environment. Deterministic deployment is recommended and even necessary for expensive sensors or when their operation is significantly affected by their position, which includes being in a populated area, underwater applications, or nodes equipped with imaging or video sensors. On the other hand, random deployment is the best choice for harsh environments, such as a battle-field or disaster zone Younis & Akkaya (2008).

- **Challenges:** the distance between two nodes affects the link quality. In the case of a network, in which some nodes have a small number of neighborhoods, this node will rapidly exhaust its battery. Additionally, for a not uniform distribution, an optimal position of the CH/BS is necessary to allow the connectivity required that can enable an energy-efficient network operation to be carried out.

  Since multimedia sensors are sensitive to direction of acquisition and have limited coverage, the multimedia node must be deployed in the best place to optimize the coverage and avoid obstacles.
- **Trends:** with regard to the use case, some nodes are equipped with a camera and there is a need to study the best place to deploy them to ensure a better coverage. The other nodes (without cameras) can be deployed in a random way, although with a uniform distribution.

  In the literature, most of the applications assume that the nodes are randomly deployed in an environment that creates an ad-hoc infrastructure, such as that shown in Kandris et al. (2011), Politis et al. (2008), and others.

  With regard to the optimization of the node deployment, there are some WSN schemes proposed in the literature and which can be adapted to work in WMSN. Two techniques are highlighted here: (i) optimization of node location Kulkarni & Venayagamoorthy (2010), and Wang et al. (2008); and (ii) optimization of the Base Station location Akkaya et al. (2007).

2.2.3 Node capabilities

Depending on the application, some sensor nodes can have a different role or capability, which is related to the capacity of the nodes in terms of computation, communication, power and multimedia support. The network can be classified as either homogeneous or heterogeneous.

Most of the applications use homogeneous nodes, which have equal capabilities in terms of computation, communication and power, or are produced by the same manufacturer. However, in some applications the network is considered to be heterogeneous, because some/all of the nodes have different capabilities or roles. In this context, they are able to perform special functions, such as sensing, aggregation, or the retrieval of multimedia content.

- **Challenges:** in the case of the heterogeneous network, the node that is able to perform a lot of tasks, e.g., sensing, aggregation, or retrieval of multimedia content is likely to end up its source of energy in a short period of time.

  Most of the nodes used in the literature are constrained in terms of their processing capability, which makes it difficult for them to carry out many tasks. Additionally, due to the fact that each manufacturer uses the standard IEEE 802.15.4 for the lower layer, (although not the upper layers), each of them recommend their own implementation, which means that the motes from different manufacturers are not able to communicate with each other.
- **Trends:** the use of a heterogeneous network can be an alternative means of overcoming the problems arising from multimedia content and the restrictions of the sensor node.

Concerning the use case, the nodes are heterogeneous, and can be divided into: (i) Common nodes that are used to perform simple tasks, with limited battery supply, and restricted in terms of processing and memory; and (ii) Powerful nodes, used for data aggregation and the retrieval of multimedia content. These nodes are equipped with multimedia equipment, and solar power. Thus, they are not restricted in terms of battery and are more powerful in terms of memory and processing.

In the approaches Akyildiz et al. (2007) and Kim et al. (2011), common nodes (resource-constrained and low-power) are able to perform simple tasks, e.g., detecting scalar data, whereas powerful nodes are able to accomplish more complex tasks, e.g., data aggregation or capturing multimedia content.

2.2.4 Link Quality Estimators (LQEs)

The wireless links are unreliable and unpredictable in WSN/WMSN. This is mainly due to the fact that the nodes use low-power radios, which are very sensitive to noise, interference, and multipath distortion. In this context, it is important for the nodes to be able to quantify a value for the quality of communication between neighborhoods. This value is obtained through a Link Quality Estimator (LQE). A path is considered to be good when a link has the highest value.

Most of the routing protocols rely on LQEs as a mechanism for selecting the most stable routes, and the accuracy of the selected LQE has an impact on their performance. Thus, LQE is a fundamental building block in the design of routing protocols for WSN/WMSN Baccour et al. (2011).

- **Challenges:** LQEs which rely on a single link property, provide only a partial view of the link quality. Thus, they are not accurate, and as mentioned above, the accuracy of LQEs greatly affects the efficiency and performance of the routing protocols.
- **Trends:** Recently, two new LQEs were devised that combine four link quality metrics: (i) F-LQE: A Fuzzy Link Quality Estimator for Wireless Sensor Networks (F-LQE) Baccour et al. (2010), which combines four link quality properties, namely packet delivery, asymmetry, stability, and channel quality. The overall quality is computed as a fuzzy rule which returns the membership of the link in the fuzzy subset of good links; and (ii) Holistic Packet Statistics (HoPS) Renner et al. (2011), which incorporates four quality metrics (Short-term, Long-term, Absolute Deviation, and Trend Estimation) that provide a holistic assessment of the link and its dynamic behavior.

  Another interesting mechanism that can be used to estimate the overall quality of a link, is introduced in Butt et al. (2010). This study suggests computing and transmitting the overall quality of a link between the source and sink, and defined two thresholds to choose the best route: (i) a LQI (Link Quality Indicator) threshold which characterizes a link as a Weak Link; and (ii) a hop count threshold that determines whether or not a route is reliable enough to replace an old route.

  In the use case, the network architecture is hierarchical-based and uses a multi-hop communication between the CHs and BS. For the CH to reach the BS with higher reliability, it should select the best routes. The routing protocol uses the F-LQE as a mechanism to estimate the overall quality of a path to route its data.

  Additionally, the network must create cluster, and it also elects the CHs and non-cluster-head. Each non-cluster-head must choose the best CH to become its leader.

The choice of the best CH is made by using some LQE metrics. In this context, LQI (provided by a physical layer) is the best metric. Since the nodes have to select the CH with the minimal overhead communication, and for each received packet the nodes can obtain the LQI.

2.2.5 Mobility

Mobility Chen & Ma (2006) is one of the key challenges in wireless communications. Some nodes in a network are assumed to be either physically or logically moving closer to each other. Physical mobility refers to changes in the geographical location of the nodes during the time, i.e., movement of vehicles, animals, and humans. On the other hand, logical mobility refers to changes in network topology, e.g. adding or removing some nodes.

Mobility can be categorized as either static or dynamic. The network is considered to be dynamic if some nodes are moving in a logical way during a period of time. Otherwise, the network is considered to be static. The mobility scenario refers to the sensed phenomenon event that depends on the application. A dynamic event can be a target detection/tracking application. Forest monitoring for fire detection is an example of a static event. Most of the routing protocols assume that the network is composed of sensor nodes that are fixed in a certain position (static network).

- **Challenges:** mobility raises the problem of routing messages through the network, since the paths/routes are continually changing; this leads to an important issue regarding optimization, as well as make improvements in energy saving and bandwidth.
- **Trends:** basically most of the works in the literature take account of the mobility of the nodes or of the sink. In Deng et al. (2011) and Tan et al. (2009) are exploit the node mobility, the works consider considering an hierarchical network and a reactive node mobility to improve the target detection performance in WSN.

  The nodes near to the sink are responsible for delivering the data to the BS, which makes the lifetime of the network strongly dependent on the energy of these nodes. To overcome this problem, some works consider that the mobile sink is a way to increase the network lifetime, such as the suggestion made by Kim et al. (2010) and Yu et al. (2010)

2.2.6 Scalability

WMSN are usually composed of hundreds or thousands of nodes, which are densely deployed either inside the phenomenon or very close to it. The density in a region of interest, can range from a few to a hundred sensor nodes, to cover the whole area. Using higher density leads to more valuable information, but implies that there is more information to transmit and process.

In this context, scalability is one of the main design attributes of the sensor networks, and this must be encompassed by the protocols. The routing protocol should be scalable enough to enable it to work with a large number of nodes, and continually ensure the correct behavior of the application. Additionally, it must be adapted to scalability changes in a transparent way, i.e., without requiring the intervention of the user.

- **Challenges:** scalability must be taken into account to achieve efficient data processing, aggregation, storage and querying in WMSNs, especially when this involves a huge amount of data.

- **Trends:** as mentioned before, the use case employs a hierarchical architecture. This architecture offers considerable advantages with respect to a flat architecture in terms of scalability, lower costs, better coverage, higher functionality, and greater reliability.

2.2.7 Multimedia content

As mentioned earlier, multimedia content produces a huge amount of data. The data is compacted by employing a compress technique, such as, MPEG, H.263 and H.264 which can be classified as predictive coding techniques. The video is compressed once by the encoder (sender) and uncompressed by the decoder (receiver).

For MPEG are defined three types of frames (I, P, B-frames) are defined, where: (i) Intra, or I-frames, is the reference for all the other frames which provide a reference point for decoding a received video stream; (ii) Predictive-coded, or P-frames, provide an increased rate of compression compared to the I-frames, with a P-frame normally being 20 to 70 % the size of an associated I-frame; and (iii) Bi-directionally predictive-coded, or B-frames, use the previous and next I-frame or P-frame as their reference points for motion compensation. B-frames provide further compression, typically 5 to 40 % the size of an associated I-frame Greengrass et al. (2009).

The nodes in a WMSN are able to capture and transmit multimedia content, which can either be a snapshot or streaming content. A snapshot contains data from an event that was triggered in a short time period, e.g. an image. Streaming multimedia content is generated over a longer time period, e.g. video and audio streaming.

- **Challenges:** the nominal transmission rate for WSN/WMSN is 250 kbit/s which is defined by the IEEE 802.15.4 standard. Thus, transmitting video which requires a high data rate over the WSN/WMSN link is extremely difficult. The limitations of the sensor nodes require video coding/compression that has a low complexity, produces a bandwidth with a low output, can tolerate loss, and consumes as little power as possible.

  Furthermore, the predictive schemes for video coding techniques are not suitable for WMSN as they require complex encoders, powerful processing algorithms, and entail a high rate of energy consumption.

- **Trends:** in the use case, a multipath can be adopted to increase the bandwidth. The multimedia content will only be sent when events occur to reduce the amount of data.

  There are some works in the literature that adopt a multi-channel and multi-path approach to increase the available bandwidth. In Hamid et al. (2008) there is a design for a QoS aware routing protocol which uses multiple paths and multiple channels to ensure bandwidth and end-to-end delay requirements. In Maimour (2008) another suggested solution is shown, where multi-path routing is used to provide a sufficient bandwidth for multimedia applications.

  Currently, there are studies that aim to scale down the complexity of the computation and consumption of power that is a feature of the motion estimation and compensation of the predictive schemes. This scheme that has been suggested is classified as distributed source coding and aims to reduce the complexity at the encoder. By using this technique, the encoder can be simple and low-powered, while the decoder will be complex and loaded with most of the processing and energy burden. Examples of distributed source coding are Wyner-Ziv Aaron et al. (2004) and PRIZM Puri & Ramchandran (2002).

2.2.8 Energy considerations

The motes are usually equipped with a small battery as an energy source, which restricts the supply of energy. The best way of overcoming this drawback would be to have nodes that are energetically self-sustainable, e.g. equipped with battery recharge/replacement or solar power, but in some cases this may not be feasible, or at least, inappropriate.

The nodes consume energy in tasks such as sensing, communication, and data processing. However, they use up more energy in data communication, which involves both data transmission and reception. As has been shown throughout this section, all of the discussed topics raise serious issues regarding energy consumption. This will have to be solved in the future by reducing the amount of work done by the node and in particular, by reducing the number of transmitted packets.

It should be pointed out that it is desirable to find methods for discovering an energy-efficient route, and route data from the sensor nodes to the BS, in order to improve the network lifetime.

- **Challenges:** as mentioned earlier, multimedia content produces a huge amount of data which has to be delivered over the network. Hence, there is a risk that the node that is transmitting or routing multimedia data might quickly drain its energy. The main difficulty is to achieve reliability in data delivery packets, with a minimal consumption of energy, while increasing the lifetime of the network.
- **Trends:** by focusing on the use case, the multimedia nodes will consume more energy which is needed to capture and transmit multimedia content. To overcome this problem, these nodes will be equipped with solar power to increase the energy source. As mentioned before, the application is event-trigger so that it can reduce the amount of multimedia data. This will prevent these nodes from consuming more energy and using up its energy resources.

  Additionally, the CHs will use the remaining energy of its neighborhoods to the CHs and select the best route to reach the BS. This scheme prevents a node with higher LQEs and low remaining energy from becoming the best route. Otherwise, this node will always be selected as the best route and will use up all its energy.

  Recently, there have been some studies that have demonstrated that the nodes must be energetically self-sustainable, i.e., equipped with battery recharge, as shown in Abu-Baker et al. (2010). Another proposal takes into account the energy required for the route selection, such as is shown in PEMuR Kandris et al. (2011). These studies compute the difference between the residual energy of a CH and the energy required to route a message between two sequential CHs. The path with the highest value is selected as the best route.

2.2.9 Quality-of-Service (QoS)

Traditionally, the main goal of QoS is to provide a set of measurable services at network/packet layer in terms of delay, jitter, available bandwidth, and packet loss, with the aim of assessing the quality level of multimedia from the perspective of the network.

Due to the difference between WMSN and other wireless networks, the QoS requirements are different for WMSN. For Chen & Varshney (2004), some QoS parameters are required to measure the delivery of data in an efficient and effective way. Moreover, for Alves et al. (2009) QoS should be seen and addressed from a more extensive and holistic perspective, and instantiated in a wider range of properties, such as heterogeneity, energy-sustainability, timeliness, scalability, reliability, mobility, security, cost-effectiveness and invisibility.

- **Challenges:** sensed data (multimedia or scalar) should be delivered at the sink within a certain period of time, otherwise, the data will be useless. Thus, during the design of a routing protocol, QoS metrics such as end-to-end delay, jitter, loss, and throughput should be taken into account.
- **Trends:** to provide higher throughput and minimal end-to-end delay for multimedia data, the protocol can use packet differentiation in a way that allows multimedia packet to be given a higher priority than scalar data. Additionally, the packets must be assigned a deadline, since any data arriving later than the deadline are simply useless. Thus, before forwarding a packet, the nodes look for the deadline, and drop them if the deadline has expired.

  In Hamid et al. (2008) a QoS-aware routing protocol is shown for WMSN, which provides packet delivery over multi-path and multi-channel. The main purpose of this proposal is to support a high data rate while meeting the required deadline. Thus, the multimedia packets can be delivered to the destination with their bandwidth and delay requirements.

  In addition, there are some protocols that have been inspired by ant colonies, such as in ASAR: an ant-based service-aware routing algorithm for multimedia sensor networks Sun et al. (2008), which provides a QoS routing model for WMSN. It chooses appropriate paths for different QoS requirements from different types of services based on ant colonies.

2.2.10 Quality-of-Experience (QoE)

Recently, QoE has grown in importance in the wireless networks and is now able to provide mechanisms to overcome the drawbacks of the QoS schemes regarding the subjective aspects of human perception. QoE metrics have employed important role to measure the quality level of multimedia content based on the perspective of the user Rowe & Jain (2005), De Vleeschauwer et al. (2008), and Serral-Gracià et al. (2010).

Several objective QoE metrics have been formulated to estimate/predict (based on mathematical models) the quality level of multimedia services in the perception of the user. The main objective metrics are as follows: Peak Signal to Noise Ratio (PSNR), Structural Similarity (SSIM) and Video Quality Metric (VQM).

The PSNR is the most traditional objective metric and compares (frame by frame) the quality of the video received by the user with the original video. The value of PSNR is expressed in dB (decibels). For a video to be considered of good quality, it should have an average PSNR of at least 30dB.

The SSIM is a measurement of the structural distortion of the video, which trying to obtain a better correlation with the user's subjective impression, where the values vary between 0 and 1. The closer the metric gets to 1, the better the video quality.

The VQM metric measures the "perception damage" the video experienced, by drawing on the Human Visual System (HVS) characteristics, including distinct metric factors such as blurring, noise, color distortion and distortion blocks. VQM obtains values between 0 and 5, where the closer to 0, means a better video quality.

- **Challenges:** the main problems are related to how to devise a new real-time and non-reference metrics to evaluate the quality level of multimedia content in WMSNs. In addition, it is also expected that there will be further routing protocol extensions with user perception.
- **Trends:** new CODECs will be developed to allow the distribution of multimedia content in WMSNs with quality level support and low energy consumption Misra et al. (2008). Cluster-based routing solutions with QoE will be used to provide high quality video distribution with energy-efficient assurance. QoE-awareness in routing protocols will create a new multimedia era in WMSNs.

2.3 Concluding remarks

From our perspective, there is no doubt that the main challenge in designing a routing protocol for WMSNs is to find an optimal trade-off between energy consumption, multimedia transmission, and the ability to meet QoS/QoE requirements (e.g., by using LQE). Additionally, the routing protocol must be sufficiently scalable, be able to work with heterogeneous environments, and, in the case of node mobility, be self-organized with a low consumption of energy.

3. State of the art for routing protocols in WMSNs

Several routing protocols were proposed for the WSNs, but the new characteristics and constraints imposed by the multimedia content made them unsuitable for WMSNs. Thus, routing protocols for WMSNs are still an open and hot field for researchers.

The recent proposals for WMSN aim to meet the QoS requirements, by applying modifications to the previous protocols for WSN or offering new solutions/mechanisms. In the following section, some promising routing protocols for WMSN will be examined. They are either a modification to an existing scheme or a new scheme.

3.1 Extensions of proposed routing protocols for WSN

Researchers have often suggested making extensions to existing protocols to overcome some of the drawbacks and improve the network performance. In the following section, some of these studies are explained in detail.

3.1.1 Multimedia streaming in large-scale sensor networks with mobile swarms

The study in Gerla & Xu (2003) aims to support high quality multimedia streams in a sensor network, by adopting the Landmark Ad-Hoc Routing (LANMAR) protocol Gerla et al. (2000). The network architecture is a kind of hierarchical architecture, where the nodes are divided into groups (called swarm groups), and each group has a leader (a swarm node) which is selected in a dynamic way. Each group is formed of nodes that are physically close to each other, and usually share the same mobility pattern.

In terms of node capabilities, the swarm nodes are powerful and equipped with high quality video cameras, long-range radio and a high channel bandwidth. Additionally, they can be equipped with satellites, and move at a relatively high speed. An example of a swarm node is a tank or Unmanned Aerial Vehicle (UAV). The other nodes carry out simple, and basic functionalities, such as, detecting intruders and monitoring changes in the environment.

The sensor nodes are deployed in an environment that covers a very large scale field, as illustrated in Figure 4. They detect intruders or monitor environmental changes, and can be characterized as an event-trigger application. If a sensor node detects an event in a given area, one or more mobile swarms are directed to that area to help forward the multimedia streams with high quality.

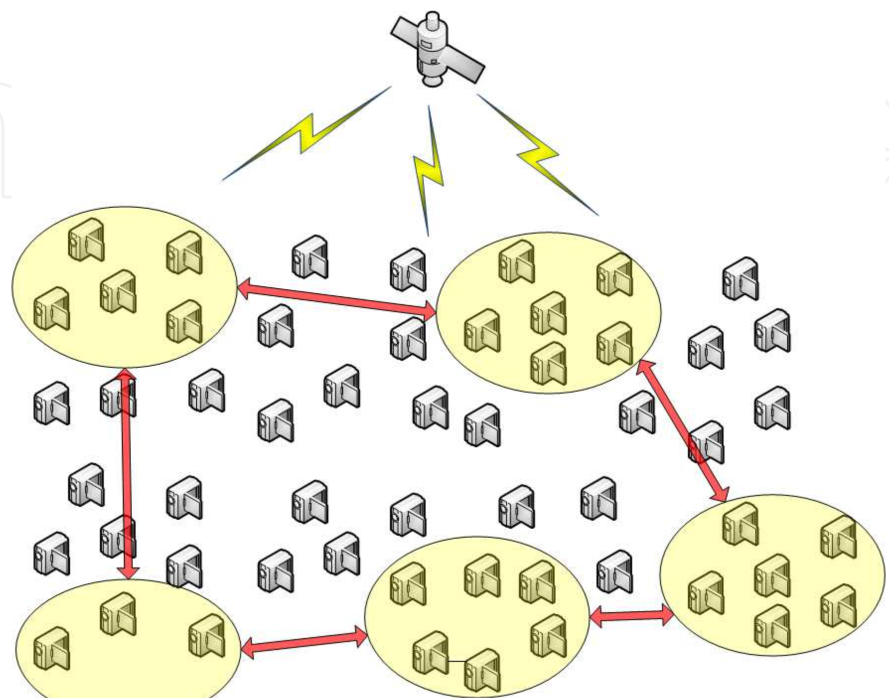

Fig. 4. Overview of a large-scale sensor network enhanced by mobile swarms

A normal radio installed in a swarm node, is sometimes not powerful enough to reach other swarms. To overcome this problem, this study recommends the adoption of a Mobile Backbone Network (MBN) for multiple swarms. This will allow the mobile swarms to communicate and exchange information with each other by using satellite communication or MBN.

This idea also suggests the use of the LANMAR routing protocol integrated with MBN, where the packets are routed through the nearest backbone node. Furthermore, this node forwards the packet through a MBN to a remote backbone node near the remote swarm node. The remote backbone node sends the data to the remote swarm node or directly to the destination if it is within its scope. This will greatly reduce the number of hops.

The study uses an event-driven approach which reduces energy consumption. However it uses satellite communication to transmit multimedia data of a high quality. This is inappropriate since this kind of communication can consume more energy, and satellite communication is out of the approach of WMSN.

3.1.2 Delay-constrained high throughput protocol for multi-path transmission over Wireless Multimedia Sensor Networks

The work proposed in Li et al. (2008) is an extension of the Directed Diffusion (DD) Intanagonwiwat et al. (2000) routing protocol which was proposed for WSN. DD has been used for sensor networks because of its scalability and energy efficiency. However, DD is a single path routing protocol, which means that the path with the lowest delay is selected as the best route. As already mention in the previous section, a single path is not suitable for multimedia transmission.

The aim of the proposed extension of DD is to provide support for multimedia streaming over WSNs. To achieve this goal, the protocol uses a multipath with a high quality link and low latency. This study considers a flat network, with stationary nodes or with a reduced mobility, that uses the same channel to communicate and where all the links are symmetrical.

In addition, the scheme does not take specific multimedia QoS requirements into account, such as throughput or loss which are used to guide the routing decision process, or prioritized packet scheduling to avoid a fast depletion of energy in the sensor nodes. However, the work considers a deadline, since any data arriving later than the deadline are simply useless.

The main goal of this proposal is to find multiple disjoint paths with a high throughput and low end-to-end delay. To maximize throughput and minimize delay, a metric was proposed to select the best route, which is called of Cost_p. This replaces the "pure delay" that was used in DD. Cost_p can be defined as a product of expected transmission count (ETX) and delay.

A further point is that the closest nodes interfere with each other's communication. A node with a poor Signal-to-Noise Ratio (SNR), which is indirectly used to estimate ETX, implies a low value of Cost_p. In this case, with the use of the proposed metric, the node is less likely to be selected as the best path.

Another suggested alteration for DD is to reinforce multiple paths to the sink to obtain a disjoint path from the source to the sink and match the multipath requirements. The proposed protocol is able to find more than the required number of paths, because some paths may not be reinforced if a disjoint node is not found or the deadline has expired. If two nodes try to reinforce a path that converges to the same node, the first one that reinforces it will be selected.

Although the work uses multi-paths to increase the available bandwidth, the proposal adopts the continuous data sensing and delivery model, with a flat network, and as well as this, all the nodes are equipped with a camera. The nodes are continually capturing multimedia data, and can forward them. Thus, it makes the protocol not energy-efficient.

3.1.3 Power Efficient Multimedia Routing (PEMuR)

In Kandris et al. (2011) a Power Efficient Multimedia Routing (PEMuR) is proposed, which is an extension of the Scalable Hierarchical Power Efficient Routing (SHPER) protocol Kandris et al. (2009). PEMuR aims to provide an efficient video communication over WMSNs and is based on a combination of hierarchical routing and video packet scheduling models. The proposal ensures low power consumption in all the sensor nodes and a high perceived video.

This study examines a hierarchical network which assumes the coexistence of a BS and a set of homogeneous sensor nodes. They are randomly distributed within a delimited area. The base station is located at a position that is far from the sensor field. All the nodes (BS and nodes) are stationary, as can be seen in Figure 5. However, the network nodes are intended to be energy constrained.

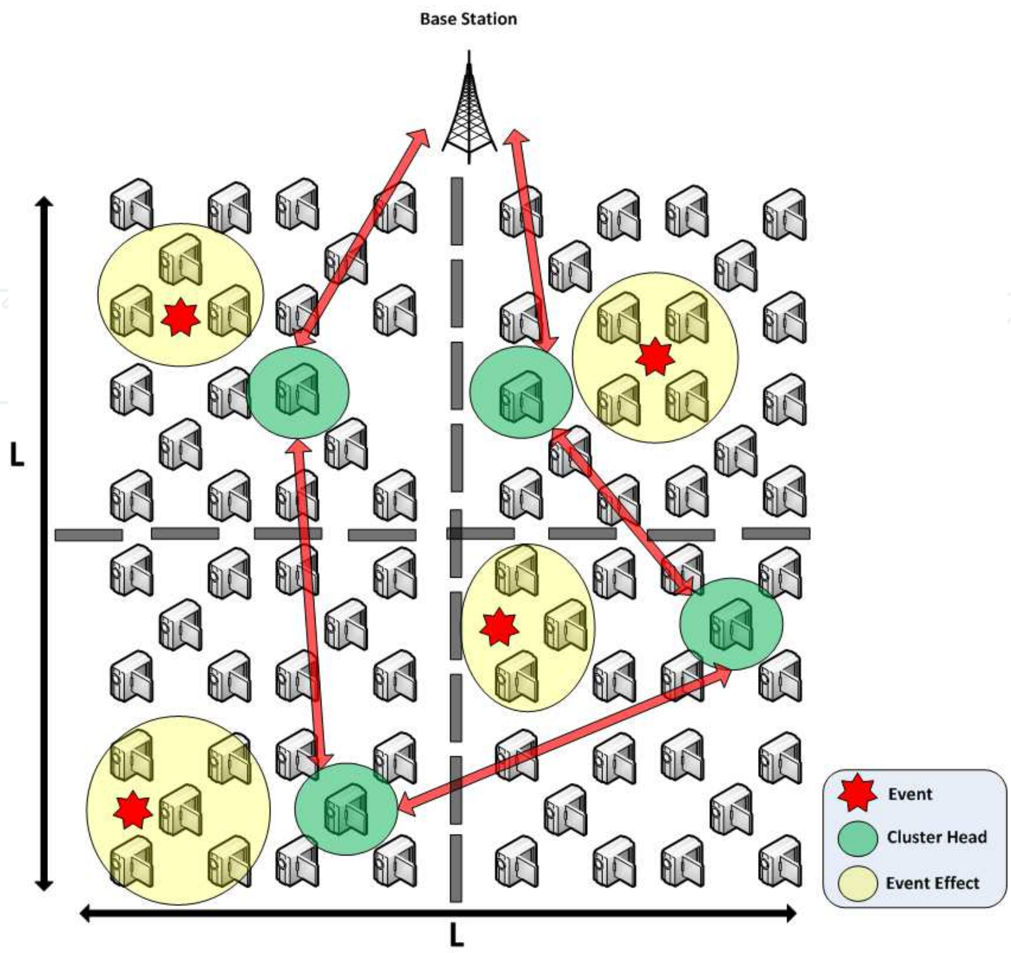

Fig. 5. Architecture scheme adopted by PEMuR

The proposed algorithm combines the benefits of the use of energy-efficient hierarchical routing with a distortion prediction model to drop packets. A time slot is assigned to each node, and the transmission only occurs when an event is detected.

The video sequence is encoded in accordance with the H.264/AVC standard. The protocol provides a packet scheduling algorithm that allows the reduction of the video transmission rate with a minimum possible increase of distortion. This algorithm is useful, because there are some cases in which the transmission bandwidth required from the sensor node exceeds the capacity limit of the shared wireless channel. Thus, each sensor node decides which video packets should be dropped so that it can reduce its current transmission rate.

To select the best route, PEMuR enables a selection of the most energy-efficient paths, by managing the network load according to the residual energy of the nodes and prevents unnecessary data transmissions by adopting a proposed energy threshold. The nodes compute the difference between the residual energy of the CH and the energy required to route a message between two sequential CHs. The path with the highest value is selected as the best route.

However, the protocol only uses the remaining energy to estimate the best routes. This means that the proposal is neither reliable nor energy-efficient. This scheme should involve a combination of some LQEs with remaining energy to find the best routes. Multi-path and multi-channel approaches should be adopted by the protocol to increase the available bandwidth that is required to transmit multimedia content.

3.2 New solutions for routing protocols in WMSN

In the following section, some important examples of new routing protocols will be investigated.

3.2.1 ASAR: An ant-based service-aware routing algorithm for multimedia sensor networks

In Sun et al. (2008) an ant-based algorithm, described as ASAR, is recommended for routing in WMSNs. The protocol provides support for three kinds of services: (i) event-driven (R-service), where the applications tend to be delay and error intolerant. This service should meet higher real-time and reliability requirements; (ii) data query (D-service), are services with both error intolerant and query-specific delay tolerant applications. It needs to be supplied with relevant data that is as reliable as possible. However, it tolerates query-specific delay; and (iii) stream query (S-service), are services with delay intolerant, but query-specific error tolerant applications. Additionally, packet losses can be tolerated within a certain limit.

The proposed routing protocol takes into account three different types of services (R/D/S), and four QoS requirements (latency, packet loss, energy consumption and bandwidth). Thus, it aims to maximize the use of the network and improve its performance. An ant-based algorithm was recommended to select an optimal path, together with an Ant-based Service-Aware Routing algorithm (ASAR).

The ASAR algorithm is running in all of the CH, and three available paths are periodically found for three types of services. The R-service requires less bandwidth and a path with lower traffic and higher SNR is an attractive solution. For D-service, a path can be used with significant congestion and a higher SNR on each link. Finally, a path with less traffic and lower SNR may be better for S-service. However, all of these kinds of services have the same goal, which is to reduce energy consumption and extend the network lifetime. Moreover, the selection of three paths for each service can prevent link congestion, when multiple kinds of services reach a node at the same time.

When selecting the paths, each CH generates ants for each type of services that depends on a proposed objective function, and a pheromone value for each path. Different paths from the CH to the BS are found which meet different QoS requirements. The pheromone value on the sink is quantified to decrease the transmission frequency of reverse ants, and this leads to a more rapid convergence of the algorithms and helps to optimize the network resources.

A system which uses bio inspirat schemes, e.g., ant colonies, is not usually explored in real applications. This is because it involves exchanging a lot of messages to discovery routes. Thus, it increases the communication overhead, and decreases the network lifetime. Another problem is the lack of multi-paths and multi-channels.

3.2.2 Design of a QoS-aware routing mechanism for Wireless Multimedia Sensor Networks

The work Hamid et al. (2008), presents a QoS-aware routing protocol to support a high data rate for WMSNs. The routing protocol works in a distributed manner to ensure bandwidth and end-to-end delay requirements of real-time data, and maximize the throughput of the non-real-time data.

The protocol targets applications of the WMSNs, where the nodes produce multimedia contents from the deployed area to deal with both the critical and general data. This study takes into account the fact that it is a static, flat and heterogeneous network, as shown in Figure 6.

The nodes are able to perform a wide range of tasks, e.g., sensing multimedia and scalar data. However, a subset of nodes has higher processing capabilities, which allows it to perform in-network processing, such as data aggregation and to discard redundant data. The sensor nodes are equipped with a multi-channel radio, which means that the nodes are capable of transmitting or receiving data on one channel at a given time.

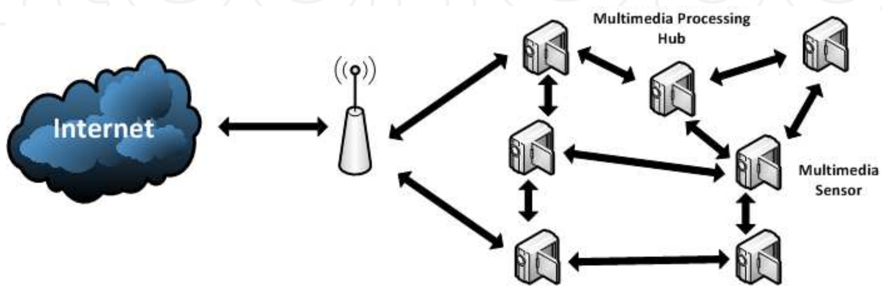

Fig. 6. The network model adopted

The proposal takes account of real-time and non-real-time data of multimedia and scalar content. The data originated from various types of events and has different levels of importance. The incoming packets are classified according to their degree of importance at each node, and then are sent to the appropriate queue. As well as this, there is a scheduler which is used to schedule the packets according to delay and bandwidth requirements.

The proposed routing protocol uses multi-path and multi-channel techniques, to increase the bandwidth. The routing decisions for real-time and non-real-time traffics are taken according to Path-length-based Proportional Delay Differentiation (PPDD). To meet the bandwidth requirements, a QoS packet scheduling technique was employed to provide a dynamic bandwidth adjustment. The PPDD device was used to meet the delay requirements.

The nodes choose the paths/channels to route their packets and meet the bandwidth and delay requirements. Additionally, each sensor node knows its next 2-hops available path, and the collision-free channel assignment. Throughout the network, the real-time packets that do not meet the deadline requirement are discarded. For best-effort traffic, alternative paths are used to balance the traffic, and the processing hubs perform data aggregation to reduce the amount of data that is transmitted through the network.

The main drawback of this is that it involves the use of a flat network. As mentioned before, in this architecture, all the nodes can forward packets, and multimedia data generates a lot of packets that have to be forwarded. Thus, this proposal is not energy-efficient.

3.3 Final considerations of proposed routing protocols

This section addresses important issues related to relevant routing protocols for WMSNs. They represent new solutions or extensions/improvements of existing protocols. The protocols that have been outlined rely on an ant colony, multipath, multi-channel, and cost function to define the best routes. The protocols attempt to provide QoS and efficient video transmission over WMSNs, as summarized in Table 1. However, they are inefficient in terms of providing reliable communication and maximizing the lifetime of the network.

Protocols	Mobility	Architecture	Multi-Path Multi-Channel	Data sensing and delivery model	Node Capabilities	Bio inspirat
LANMAR Gerla & Xu (2003)	Some mobile nodes	Hierarchical	No	Event-driven	Heterogeneous	No
DD-Extension Li et al. (2008)	Static or reduced mobility	Flat	Multi-path	Continuous	Homogeneous	No
PEMuR Kandris et al. (2011)	Static	Hierarchical	No	Event-driven	Homogeneous	No
ASAR Sun et al. (2008)	Static	Hierarchical	No	Event-driven Query-driven	Homogeneous	Ant-colony
QoS-aware Hamid et al. (2008)	Static	Flat	Multi-path Multi-channel	Event-driven	Heterogeneous	No

Table 1. Main Features of Routing Protocols

In general, the routing solutions inspired in ant colonies, are not explored in real applications because these schemes have a long adaptation time to react to changes in the topology and also during the setup phase. Additionally, in some cases, they are not energy-efficient since they involve exchanging a lot of messages to discovery routes.

At the same time, there is no doubt that multi-paths and multi-channels are the best approaches to increase the network bandwidth in WMSNs, although, these schemes affect the other layers, such as MAC and transport layers. Further proposals must be designed so that they can find a satisfactory solution to this problem and cover routing, transport, and MAC layers.

As mentioned in the previous section, QoS is not accurate enough to achieve higher video quality in wireless multimedia transmissions. Thus, QoE is the most suitable scheme to overcome the main drawbacks of QoS regarding user perception. This approach has been used in wireless communication, e.g., mesh network, and its implementation in WMSNs is now being studied.

Finally, this last comment also applies to network topology and the nodes feature. The best network architecture for WMSN is hierarchical/cluster-based. This kind of architecture offers considerable benefits, such as, scalability, lower cost, better coverage, higher functionality, and greater reliability. The multimedia nodes should be more powerful and self-sustainable in terms of energy, since retrieving multimedia content requires higher processing and energy.

4. Final considerations

In wireless sensor network, the access and distribution of multimedia applications/services with quality level continue to be an attractive research area, since they allow the emergence of a wireless multimedia sensor network. WMSN is a network of wirelessly interconnected sensor nodes equipped with multimedia devices, and can be expected to offer a wide range of potential applications in both civilian and military areas.

In most of the applications in WMSN, the nodes are densely deployed in a large field. Thus, some nodes need to use multi-hop communication. In this context, the nodes rely on a routing protocol to deliver the multimedia content and scalar data to BS. WMSN has several characteristics that distinguish it from other wireless networks. Thus, there are some challenges to overcome during the design of a reliable, fairness and energy-efficient routing protocol for WMSNs.

The objective of this Chapter was to highlight important topics in WMSN, namely the challenges and current trends in routing protocols. The main issues that affect the designer when designing the routing protocol are explored to provide an energy-efficient, reliable and fair distribution of resources as well as a quality level of support.

We hope that this chapter will help to improve the understanding of the issues and challenges that lie ahead in WMSN and the examination of the routing issues will serve as a stimulus for designers, engineers, and researchers to seek innovative solutions in the future.

5. Acknowledgments

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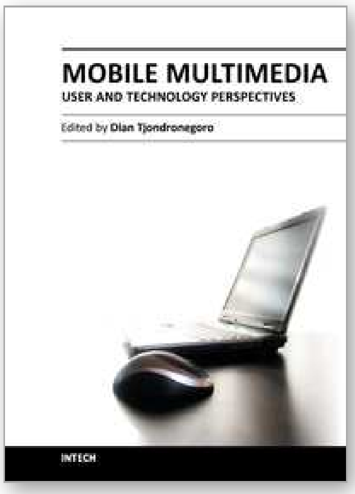

Mobile Multimedia - User and Technology Perspectives

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As multimedia-enabled mobile devices such as smart phones and tablets are becoming the day-to-day computing device of choice for users of all ages, everyone expects that all mobile multimedia applications and services should be as smooth and as high-quality as the desktop experience. The grand challenge in delivering multimedia to mobile devices using the Internet is to ensure the quality of experience that meets the users' expectations, within reasonable costs, while supporting heterogeneous platforms and wireless network conditions. This book aims to provide a holistic overview of the current and future technologies used for delivering high-quality mobile multimedia applications, while focusing on user experience as the key requirement. The book opens with a section dealing with the challenges in mobile video delivery as one of the most bandwidth-intensive media that requires smooth streaming and a user-centric strategy to ensure quality of experience. The second section addresses this challenge by introducing some important concepts for future mobile multimedia coding and the network technologies to deliver quality services. The last section combines the user and technology perspectives by demonstrating how user experience can be measured using case studies on urban community interfaces and Internet telephones.

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