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# A Taxonomy of Routing Protocols in Wireless Sensor Networks

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***Abstract*—**The Internet of Everything (IoE) presents today a very attractive and motivating field of research. It is basically based on Wireless Sensor Networks (WSNs) in which the routing task is the major analysis topic. In fact, it directly affects the effectiveness and the lifetime of the network. This paper, developed from recent works and based on extensive researches, proposes a taxonomy of routing protocols in WSNs. Our main contribution is that we propose a classification model based on nine classes namely application type, delivery mode, initiator of communication, network architecture, path establishment (route discovery), network topology (structure), protocol operation, next hop selection and latency-awareness and energy-efficient routing protocols. In order to provide a total classification pattern to serve as reference for network designers, each class is subdivided into possible subclasses, presented, and discussed using different parameters such as purposes and characteristics.

***Keywords*—**WSNs, sensor, routing protocols, survey.

## I. Introduction

In the current decade, WSNs, which are a system of small collaborative objects called Sensors used to collect information or physical parameters etc. in an area where they are deployed to ensure a continuous control through wireless communication, have become a subject of interest in a wide range of applications such as vehicular networking, surveillance, healthcare, monitoring system, fire detection, military, and so forth, and it has become a hot research area especially with recent advances in embedded systems and wireless communication technologies [1]-[3].

Routing task and communication between Sensor nodes which have particular characteristics in terms of energy, transmission range, computational and storage capacity is the major responsible for the management of the network resources. Therefore, it acts directly on the network lifetime [4]-[6]. Recent researches interested in routing in WSNs, have led to the appearance of a variety of routing protocols that aim to overcome the severe hardware and resources constraints of nodes since the variety of applications makes a minority of routing protocols inefficient for sensor networks across all applications [7].

The main contribution of this paper is to present a new in-depth classification model of routing protocols in WNS in terms of precision and clarity. We propose an overall taxonomy containing nine possible categories of routing protocols namely Application type, Delivery Mode, Initiator of communication, Network architecture, Path establishment (Route Discovery), Network topology (Structure), Protocol operation, Next Hop selection and Latency-aware and energy-efficient Routing protocols. We discuss each class under the appropriate category.

The rest of the paper is organized as follows: Section II, presents the challenges and routing factors of WSNs. Section III presents our proposed taxonomy of routing protocols. Lastly, we conclude the paper and highlight our future work in Section IV.

## II. WSNs Design Challenges and Routing Factors

Depending on the application requirements, the characteristics of individual sensors, the behavior of a network, and the nature of sensor fields, different impacts on the network design in terms of network performance, communication and capabilities have been considered.

One of the main design objectives of WSNs is to maintain the QoS and the effectiveness of communications while trying to enhance the lifetime of the network. Oftentimes, the WSN has to satisfy several constraints and to fulfill the many requirements. In the following, we represent some of the routing challenges and design issues facing WSNs.

### *A. Limited Energy Capacity*

The fact that sensor nodes are limited battery powered devices (<0.5 Ampere/hour 1.2 Volt), and due to the tough nature of WSNs applications environment, it is became undesirable or impossible in most cases to replace a sensor's battery once it is exhausted which presents a basic limiting factor for the node's lifetime and makes several tasks greatly affected by energy considerations such as the sensing task, the process of setting up routes in a network, processing task etc. which presents a big challenge for the network designers. Communication in WSNs is the most expensive operation in terms of energy, that is why the routing protocols should be as energy efficient as possible to extend sensors lifetime, and consequently prolong the network lifetime because a malfunctioning of some sensor nodes due to a depletion of energy can cause several problems such as intermittent connectivity, significant topological changes and might require rerouting of packets and reorganization of the network in

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several cases. In order to improve the energy efficiency of WSNs, routing protocols adopt many strategies which optimize the consumption of energy and keep the desired Quality of Service (QoS) without hampering the routing accuracy.

*B. Node Deployment*

Depending on the application and the environmental conditions, node deployment can be either deterministic (manual) or randomized (self-organizing). It is a very important task that directly influences the performance of the routing protocol. In self-organizing systems, usually the sensor nodes do not follow a regular pattern and they need to create an infrastructure in an ad-hoc manner. In that infrastructure, nodes use the route discovery to establish paths in order to organize themselves to ensure data routing. The high density, the position of the nodes and the uneven distribution must be taken into account to ensure the performance and the energy efficiency of the network. However in deterministic systems, nodes are arranged manually with pre-arranged locations to maximize the energy efficiency of the network and predetermined path are built to route data from nodes to the sinks. In most applications, the sensor nodes remain static after deployment.

*C. Sensor Location*

Several factors can affect the topology of WSNs such as energy, nodes status (active, sleep, died) and dynamic changes due to sink mobility or target mobility etc. These changes affect the neighborhood topology of a sensor node, hence, the communication structure, which can cause several routing problems. Consequently, the routing protocol should be able to adapt to these changes that is why the most of existing routing protocols assumes that the sensor nodes must to learn about their locations using the Global Positioning System (GPS) [8], [9] or others localization techniques [10] which presents another challenge which has to be managed in order to provide a kind of topology-awareness such that the neighborhood of each node is discovered and the routing decisions are made accordingly.

*D. Dynamic Network*

WSNs topology is usually assumed to be static, but in many applications mobility of sensor nodes or sinks is required and even the sensed phenomenon can be either dynamic or static according to the nature of the application, hence, WSNs will have a dynamic aspect which should not affect the task of routing data in the network. Routing protocol must support this dynamic aspect to ensure a complete and efficient routing.

*E. Hardware Resource Constraints*

In order to keep the tiny size of the sensors and to reduce manufacturing costs, nodes have limited hardware resources:

- Limited storage capacities: memory and buffer in sensor nodes are kept small and does not exceed tens of Kbytes.
- Limited processing capabilities: nodes have a low computational capability because of its limited processing capacities.
- Restricted coverage capabilities: Nodes can only cover a limited physical area of the environment due to the small sensing range which makes a given sensor’s view of the environment limited both in range and in accuracy.
- Weak wireless communication: nodes communication in WSNs, which is the most expensive operation in terms of energy, uses a wireless medium. The bandwidth of the wireless channel is limited as well as the transmission power of sensor nodes that is why wireless communication can be disturbed by interferences from the environment.

These hardware constraints have to be considered alongside with the limited energy in software development and network protocol design for WSNs.

*F. Data Aggregation and Gathering*

An event can be detected by more than one sensor; hence, nodes may generate significant redundant data. These similar packets can be aggregated to reduce the number of transmissions as the calculation is much cheaper than wireless communication in terms of energy. This technique use some of aggregation functions such as suppression, min, max and average which will help in energy minimization and traffic optimization in routing protocols so that network lifetime will be enhanced [11], [12]. Signal processing can also be used for data aggregation by combining the incoming signals in a node in order to reduce the noise in them.

*G. Scalability*

Scalability is a very important factor in WSNs where the network size can grow rapidly to handle and respond to different events and to applications requirements. The number of sensor nodes deployed in the sensing area may exceed some hundreds or thousands of nodes and a routing protocol should be designed to adapt and to work consistently with this huge number of sensors which may not be similar in terms of energy, processing, sensing, and communication interfaces.

*H. Fault Tolerance*

The topology of WSNs is consistently prone to frequent changes depending on the state of the nodes (sleep mode, physical damage, lack of power) [13], [7], the links status (link failure) and the environment parameters (interferences, intrusions, fire, flood ...). These changes should not in any way affect the overall network performance and the routing protocol should be able to provide robustness to node failures and overcome these problems by finding the alternate path to the data collection point or sink to sustain sensor network functionalities without any interruption.

*I. Diverse Sensing Application Requirements*

WSNs have different applications. Each application has its own specifications and constraints; hence, there is no routing protocol which can fully meet the requirements and the criteria of all applications. Therefore, the type of the application has to be considered in the network protocol design to optimize as much as possible the routing task and consequently to enhance the network performance.

*I. Heterogeneity*

The nodes in an application may have different roles and different characteristics in terms of their sensing capabilities, memories, computation power, wireless interfaces etc. This heterogeneity may cause many technical issues related to communication and data routing and it is up to the routing protocol to overcome them.

*J. Quality of Service*

Satisfying the QoS for an application or for a network is one of the basic principles of the routing protocols design in WSNs. The routing protocol must deal with the loss of data packets, guarantee their sequencing and ensure the latency (end-to-end delay) which is a very important factor in WSNs; it is the time required for a packet to get from one node to the sink or vice versa or also to make a round-trip (from source to sink and from sink back to the source). In fact, data should be delivered within a certain period of time; otherwise the data will be useless.

*K. Data Reporting Model*

Data delivery model determines when the sensed data has to be delivered. Depending on the application type, data reporting can be categorized into four classes: time-driven (continuous), event-driven, query-driven or hybrid [14], [15]. In the continuous delivery model, data is sent periodically. This model is suitable for applications based on periodic data monitoring. In the event-driven and the query-driven models data transmission start only when the event occurs, or a query is generated by the sink. The hybrid model is a combination of the three previous models. The routing protocol is highly influenced by the data reporting model and should be adapted to the model adopted by the application.

*L. Production Cost*

The number of sensor nodes used by an application in a sensing area may exceed, in some cases, some hundreds or more of nodes. That is why the cost of each sensor node has to be kept low which results in some limitation that the routing protocol should overcome them through various techniques.

*M. Connectivity:*

In WSNs, sensor nodes are deployed in high density to preclude them from being completely isolated from each other due to sensor node failures. The routing protocol should guarantee this connectivity as much as possible.

So, the main task of routing protocols in WSNs is to ensure reliable multi hop communication from the target area towards the sink node in an infrastructure-free topology where it is unfeasible to build a global addressing as for conventional IP architecture because of the discriminated characteristics of WSNs [16] that distinguish them from contemporary communication and wireless ad hoc networks. Many routing protocols have been proposed for routing data in WSNs and several surveys that have sought to analyze and classify these protocols according to different parameters have been published. Our work, presented in the next section, differs from these surveys where it is the deepest. In fact, it presents a novel taxonomy of routing protocols for WSNs which is, to the best of our knowledge, the most comprehensive and detailed taxonomy in terms of punctuality and preciseness.

## III. The Proposed Taxonomy of Routing Protocols in WSNS

Because of the specific characteristics of WSNs, conventional routing protocols designed for ad-hoc networks are not applicable to them. For this, several specialized protocols that conserve power and minimize network traffic in order to extend the network lifetime have been proposed. These protocols differ in various ways that is why we should find and adopt a well-defined taxonomy in order to select the most appropriate protocol for an application based on its requirements.

Based on their procedures, parameters, attributes and aspects, we proposed, in this paper, a novel comprehensive and well detailed taxonomy which divides routing protocols into nine categories as shown in Fig. 2.

A detail overview of each routing paradigm is discussed in the rest of following paragraphs

*A. Application Type*

Depending on whether the data will be sent following an event or periodically, routing protocols for WSNs can be classified into two categories: event-driven and time-driven protocols [17]. In event-driven protocols, sensed data will be sent only after a significant event triggered in the sensing region as shown in Fig. 1. These protocols can be further divided into Sink centric and Node centric protocols depending on whether decisions and sensing levels are made by sinks according to the collected information and sent to sensors nodes in the sensing area or predefined at the end-nodes. Contrary to time-driven protocols, where sensed data is periodically sent to the sink by all or special groups of sensor nodes with a prefixed or configurable reporting period.

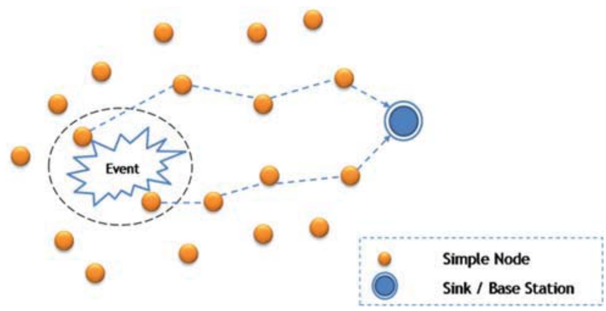


Fig. 1 Event-driven Routing Model

*B. Delivery Mode*

Routing protocols in WSNs can be classified into Real Time-protocols and Non-Real Time-protocols depending on the message's delivery requirements [18], [19]. In fact, some application only requires the successful delivery of data without temporal constraints unlike to other applications requiring a real time communication otherwise information will be useless or of lower value.

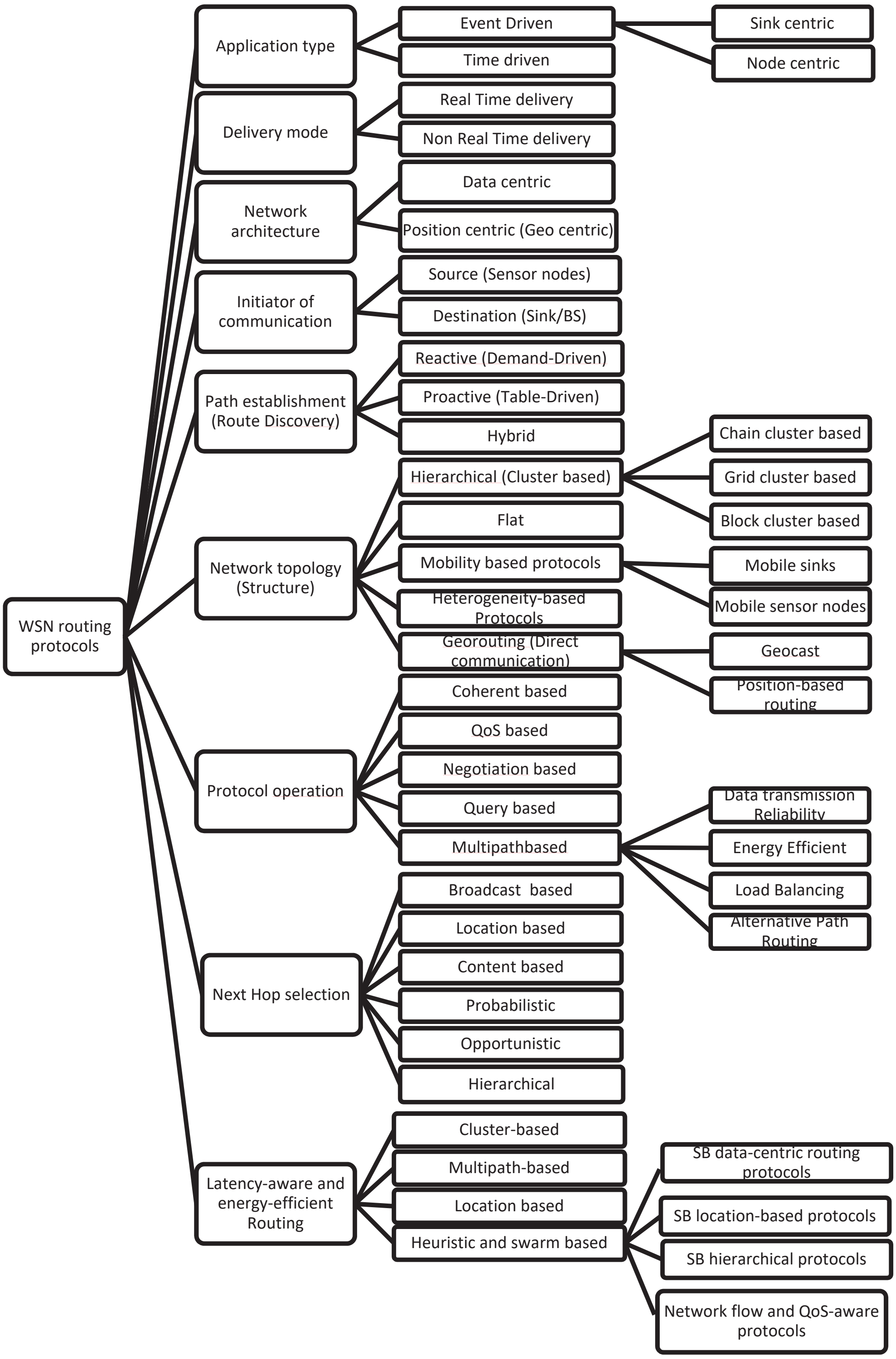


Fig. 2 Routing protocols in WSNs: A taxonomy

*C. Network Architecture*

Based on their procedures, routing protocols can be also classified according to the network into Data centric and Position centric (Geo-centric) routing protocols [20], [21]. Data centric routing protocol overcomes the limitations of the global identification systems which appear with the deployment of a large number of sensor nodes using a data naming mechanism which helps to eliminate redundant messages and to refine data filling. Contrariwise, in Position centric routing protocols sensor nodes are position aware and geographical positions are used to forward data and queries to particular regions which will eliminate the number of transmission and unnecessary queries.

### *D. Initiator of Communication*

Another way to categorize routing protocols in WSNs is to classify them based on whether routing paths are initiated by source or destination depending on whether the initiator of the communication is respectively the sensor nodes (source of sensed data) or the sink (destination of sensed data) [22].

### *E. Path Establishment*

Based on their routes discovering process from source to destination which can be established in one of three ways, routing protocols in WSNs can be also classified to into three classes namely proactive, reactive or hybrid [23], [24]. Proactive routing protocols generate and update possible paths in the form of routing table at each node before they are needed contrary to Reactive routing protocols which generate routing table only on-demand. Hybrid routing protocols Combine the characteristics of proactive and reactive mechanisms to exploit their merits in order to incorporate the benefits of pro-activity and reactivity.

### *F. Network Topology*

Routing protocols in WSNs can be also classified according to the network structure (topology) into five broad classes according to their functionalities which are: Hierarchical, Flat, Heterogeneity based, Mobility based and Geo-routing protocols [25]. In the following, we detail each of these categories.

1. Hierarchical (Cluster based): Hierarchical routing protocols [17], [24] lay out a structured network topology based on small groups of sensor nodes called clusters or clumps with a selected Cluster Head (CH) in each group used to ensure communication in the inter and intra-cluster domain as shown in Fig. 3.

These protocols can be also divided into three categories namely Block cluster based [17], Grid cluster based [26] and Chain cluster based [27]. Using Block cluster-based protocols; nodes are arranged in virtual blocks with a networking strategy responsible for ensuring communication in and between blocks. In the same way, Grid cluster-based protocols arrange nodes according to virtual grids and ensure communication between them while nodes build chains operating according to a well-defined communication strategy in the case of Chain cluster-based routing protocols.

2. Flat: The flat networking model defined by Flat-based routing protocols is specific topology is which all nodes are treated equally, have identical functionality and carry out the same tasks in gathering information [28].
3. Heterogeneity based: Some specific topologies in WSNs use several types of sensors nodes with variable characteristics in term of energy, processing capabilities, etc. Heterogeneity based routing protocols are capable to manage the data routing in such specific network topology while taking advantage of powerful nodes in order to extend the network lifetime. The heterogeneity can be of various levels; each level is formed by nodes at the same energy level [29].
4. Mobility based protocols: Nodes mobility, caused by several factors such as mobile platform and environmental conditions (wind, water, and so on) [30] lead to the appearance of two types of mobile nodes: Mobile Sensor nodes, and mobile sinks, and results in frequent changes in network's structure and introduces several problems such as routes changes, packets delivery delay, isolated areas etc. Mobility based routing protocol, either for mobile sensor nodes or mobile sinks [31], overcome these problems and aim to improve the network life time.
5. Geo-routing: Also known as Direct communication. In Geographic routing, sensor nodes are aware about their positions. Based on their data retrieval process, these routing protocols can be divided into two broad classes which are: position-based routing and geocasting. In position-based routing, data is retrieved from a single source node contrary to geocasting in which the detection of a particular event requires the collaboration of several sensor nodes in a particular region [32].

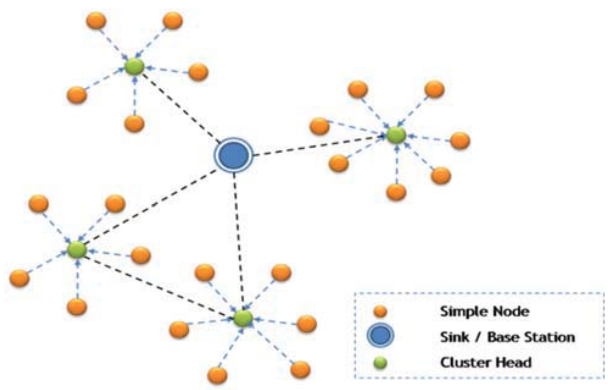


Fig. 3 Hierarchical Routing Model

### *G. Protocol Operation*

Depending on their routing operations, routing protocols in WSNs can be classified into five broad classes namely: Multipath based, query based, negotiation based, QoS based and coherent based routing protocols. In the following, we detail each of these classes.

1. Multipath based: Some routing protocols use multiple paths between source and destination instead of a single path to provide reliability and network robustness in case of node failures [32]-[34] and congestion in order to improve network performance. Multipath based routing protocols class may be further divided into four classes which are: Alternative Path Routing in which only one path, among the maintained paths, is used for data routing and will be changed by another in case of breakdown. Load balancing routing protocols [35] based on a mechanism using alternate paths are used to divert traffic when a main link becomes over-utilized to minimize the risk of traffic congestion. Energy aware multipath routing protocols

which seek to conserve energy through the selection of the routing path that reduces energy consumption as much as possible among available paths and Data Transmission Reliability routing protocol used to improve the network reliability by sending simultaneously multiple copies of data across multiple paths.

2. Query based: In the absence of geographic routing information, Query-based routing protocols [36] are adapted to ensure the routing task by sending query packets to retrieve specific information from sensor nodes. Routing paths are generated while the query propagates and will be used as a data return path.
3. Negotiation-based: Using some negotiation process between neighboring nodes based on high-level data descriptors, Negotiation based routing protocols [37] aim to conserve energy through the elimination of redundant data transmissions.
4. QoS Based: Some sensing applications require a minimum level of certain QoS metrics, e.g., reliability, delay and bandwidth. QoS based routing protocols [38] take into consideration the QoS requirements in the network in addition to minimizing energy consumption.
5. Coherent based: In order to extend the network life time, data processing in WSNs can be done in two ways using coherent or non-coherent methods [39] depending on whether sensors will locally process the data before being sent to other nodes for more processing in the case of non-coherent data processing-based routing protocols or only a minimum processing is done locally in the case of coherent data processing-based routing protocols.

### *H. Next Hop Selection*

While routing packets, nodes select their next-hop for the query and/or the response in different ways based on a set of information [40]. These protocols can be divided into six classes which are: Broadcast based routing protocols in which packets are distributed to every node in the network using broadcasting mechanism. Location based protocols using geographic information to select the next hop which eliminate the number of transmissions. Content based routing protocols used in some sensing applications operating in some networks where the communication model is not based on nodes addresses, thus next hops must be inferred from data carried by the packet. Probabilistic based routing protocols [38] with which the next hop is selected randomly among all available neighbors in order to increase load balancing in the network contrary to Opportunistic based routing protocols [41] which define and chose a next hop selection and prioritization metric. Finally, Hierarchical based routing protocols, which respect and follow a hierarchical-based scheme from the source to the destination according to which the next hops are selected as explained previously.

### *I. Latency Aware and Energy-Efficient Routing*

Depending on their procedure, routing mechanisms and design objectives such as latency and energy-efficiency routing protocols in WSNs can generally be divided into four broad subcategories which are: Cluster based protocols which, as already explained, aim to balance the efficiency on energy and network delay metrics using a specific routing scheme. Multipath based protocols which balance the traffic load in the network using multiple paths instead of a single path between a source and a destination. Location based protocol which use geographic information to ensure the network latency and to achieve maximum energy efficiency in the network, as explained earlier in this paper. Finally, Heuristic and swarm-based protocols which are inspired by behaviors observed in nature [42] as in ant and bee colonies such as the framework of Ant Colony Optimization (ACO) [43]-[45] which aims to achieve energy efficiency in order to extend the network life time. Heuristic and swarm based protocols can be further divided into four subclasses according to their functionalities namely SB data-centric routing protocols which are Data Centric based, SB location-based protocols using location information to know separating distance between particular nodes, SB hierarchical protocols which define a specific structured topology inspired from nature e.g. eggs and larvae in ant colonies are grouped into a number of small groups according to their degree of similarity and Network flow and QoS-aware protocols aiming to satisfy some QoS metrics and to deal with the loss of data packets based on some algorithms inspired from behaviors observed in nature.

## IV. Conclusion and Future Work

Routing task is the major analysis topic in WSNs. In fact, routing protocols need to deal with the severe hardware and resources constraints of sensor nodes. This paper presents a new global taxonomy distinguishing nine possible categories of routing protocols namely: Application type, Delivery Mode, Initiator of communication, Network architecture, Path establishment (Route Discovery), Network topology (Structure), Protocol operation, Next Hop selection, and Latency-aware and energy-efficient based Routing.

Our future work will be dedicated for an in-depth analysis of each of these classes under different conditions and with several experimental parameters in order to provide a punctual evaluation for recent protocols in order to facilitate the design of routing protocols for researchers and protocol designers.

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