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INVESTIGATIVE STUDY ON ROUTING METHODS FOR CRSN

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Abstract: Cognitive radio system (CRS) is a radio system which is aware of its operational and geographical environment, established policies, and its internal state. It is able to dynamically and autonomously adapt its operational parameters and protocols and to learn from its previous experience. Based on software-defined radio (SDR), CRS provides additional flexibility and offers improved efficiency to overall spectrum use. CRS is a disruptive technology targeting very high spectral efficiency. This paper presents an overview and challenges of CRS focussing the various protocols and its functions. We summarize the status of the related regulation and standardization activities which are very important for the success of any emerging technology and also studied comparison of wireless sensor networks and cognitive radio sensor network (CRSN) A particular focus is on architecture and implementation of CRSN.
Keywords: Cognitive radio system, wireless sensor networks, cognitive radio sensor network, Routing Protocols.

1. INTRODUCTION

Cognitive radio is an intelligent wireless communication system that is aware of its surrounding environment (i.e.,outside world), and uses the methodology of understanding by- building to learn from the environment and adapt its internal states to statistical variations in the incoming RF stimuli by making corresponding changes in certain operating parameters (e.g., transmit-power, carrier-frequency, and modulation strategy) in real-time, with two primary objectives in mind: highly reliable communication whenever and wherever needed; efficient utilization of the radio spectrum.[1]

In other words, once cognitive radios can find the opportunities using the “spectrum holes” for communications, cognitive radio networking to transport packets on top of cognitive radio links is a must to successfully facilitate useful applications and services. A mobile terminal with cognitive radio capabilities can sense the communication environments (e.g. spectrum holes, geographic location, available wire/wireless communication system or networks, available services), analyze and learn information from the environments with user’s preferences and demands, and reconfigure itself by adjusting system parameters conforming to certain policies and regulations. For example, when a cognitive radio mobile terminal sensed that there are Wi-Fi and GSM systems nearby while spectrum holes exist in the frequency band of digital TV, it may decide to download files from a certain Wi-Fi AP, make a phone call through GSM system and communicate with other cognitive radio users using those spectrum holes. A cognitive radio terminal could also negotiate with other spectrum and/or network users to enable more efficient spectrum and network utilization. The negotiation procedure may be facilitated from the support of network/infrastructure sides or just proceed in an ad hoc manner [13] [14].Fig. 1 shows the operations of cognitive radio sensor network.

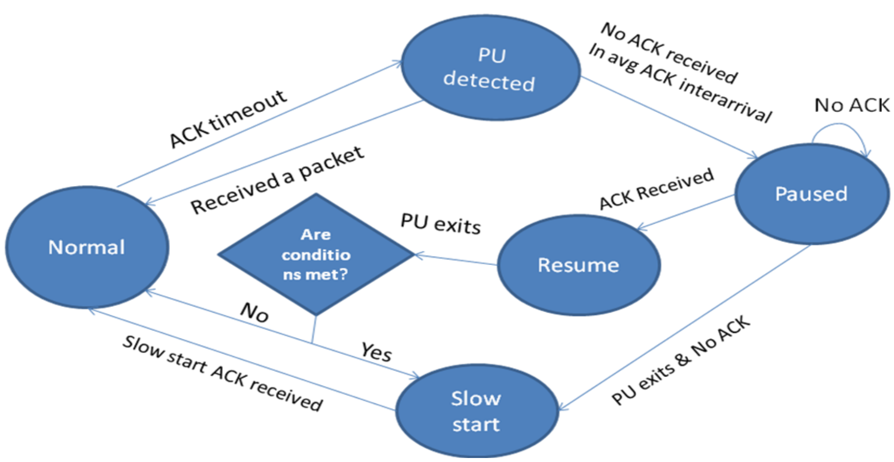

Fig.1 Operations of cognitive radio senor networks

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2. FUNCTIONS OF CRSN

The main functions of cognitive radios are:

- Power Control: Power control is usually used for spectrum sharing CR systems to maximize the capacity of secondary users with interference power constraints to protect the primary users.
- Spectrum sensing: Detecting unused spectrum and sharing it, without harmful interference to other users; an important requirement of the cognitive-radio network is to sense empty spectrum. Detecting primary users is the most efficient way to detect empty spectrum. Spectrum-sensing techniques may be grouped into three categories:
- Transmitter detection: Cognitive radios must have the capability to determine if a signal from a primary transmitter is locally present in a certain spectrum. There are several proposed approaches to transmitter detection:
- Matched filter detection: Energy detection is a spectrum sensing method that detects the presence/absence of a signal just by measuring the received signal power. This signal detection approach is quite easy and convenient for practical implementation. To implement energy detector, however, noise variance information is required. It has been shown that an imperfect knowledge of the noise power (noise uncertainty) may lead to the phenomenon of the SNR wall, which is a SNR level below which the energy detector cannot reliably detect any transmitted signal even increasing the observation time.

It has also been shown that the SNR wall is not caused by the presence of a noise uncertainty itself, but by an insufficient refinement of the noise power estimation while the observation time increases.

- Cyclostationary-feature detection: These type of spectrum sensing algorithms are motivated because most man-made communication signals, such as BPSK, QPSK, AM, OFDM, etc. exhibit cyclostationary behaviour. However, noise signals (typically white noise) do not exhibit cyclostationary behaviour. These detectors are robust against noise variance uncertainty. The aim of such detectors is to exploit the cyclostationary nature of man-made communication signals buried in noise. Cyclostationary detectors can be either single cycle or multicycle cyclostationary.
- Wideband spectrum sensing: refers to spectrum sensing over large spectral bandwidth, typically hundreds of MHz or even several GHz. Since current ADC technology cannot afford the high sampling rate with high resolution, it requires evolutional techniques, e.g., compressive sensing and sub-Nyquist sampling.
- Cooperative detection: Refers to spectrum-sensing methods where information from multiple cognitive-radio users is incorporated for primary-user detection
- Interference-based detection
- Null-space based CR: With the aid of multiple antennas, CR detects the null-space of the primary-user and then transmits within the null-space, such that its subsequent transmission causes less interference to the primary-user
- Spectrum management: Capturing the best available spectrum to meet user communication requirements, while not creating undue interference to other (primary) users. Cognitive radios should decide on the best spectrum band (of all bands available) to meet quality of service requirements; therefore, spectrum-management functions are required for cognitive radios. Spectrum-management functions are classified as:
  - Spectrum analysis
  - Spectrum decision

The practical implementation of spectrum-management functions is a complex and multifaceted issue, since it must address a variety of technical and legal requirements. An example of the former is choosing an appropriate sensing threshold to detect other users, while the latter is exemplified by the need to meet the rules and regulations set out for radio spectrum access in international (ITU radio regulations) and national (telecommunications law) legislation[13].

3. TERMINAL CAPABILITY OF COGNITIVE RADIO SENSOR NETWORKS

The capabilities of cognitive radios as nodes of CRN can be classified according to their functionalities. A cognitive radio shall sense the environment (cognitive capability), analyze and learn sensed information (self-organized capability) and adapt to the environment (reconfigurable capabilities).

Spectrum Sensing

A cognitive radio can sense spectrum and detect “spectrum holes” which are those frequency bands not used by the licensed users or having limited interference with them.

Spectrum Sharing

A cognitive radio could incorporate a mechanism that would enable sharing of spectrum under the terms of an agreement between a licensee and a third party. Parties may eventually be able to negotiate for spectrum use on an ad hoc or real-time basis, without the need for prior agreements between all parties.

Location Identification

The ability to determine its location and the location of other transmitters, and then select the appropriate operating parameters such as the power and frequency allowed at its location. In bands such as those used for satellite downlinks that are receive-only and do not transmit a signal, location technology may be an appropriate method of avoiding interference because

sensing technology would not be able to identify the locations of nearby receivers.

Network/System Discovery

For a cognitive radio terminal to determine the best way to communicate, it shall first discover available networks around it. These networks are reachable either via directed one hop communication or via multi-hop relay nodes. For example, when a cognitive radio terminal has to make a phone call, it shall discover if there is GSM BTSs or Wi-Fi APs nearby. If there is no directed communication link between the terminal and the BTSs/APs but through other cognitive radio terminals some access networks are reachable, it can still make a call in this circumstance. The ability to discovery one hop or multi-hop away access networks is important.

Service Discovery

Service discovery usually accompanies with network/system discovery. Network or system operators provide their services through their access networks. A cognitive radio terminal shall find appropriate services to fulfil its demands [13].Fig.2 shows the spectrum holes with respect to dynamic spectrum access.

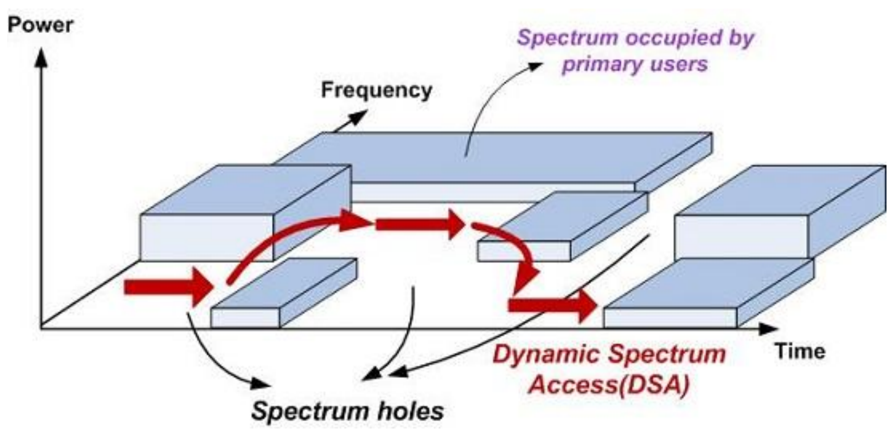


Fig.2 Spectrum holes with respect to dynamic spectrum access(DSA)

4. CLUSTERING

Clustering can be considered the most important unsupervised learning problem; so, as every other problem of this kind, it deals with finding a structure in a collection of unlabeled data. A loose definition of clustering could be “the process of organizing objects into groups whose members are similar in some way”[3]. A cluster is therefore a collection of objects which are “similar” between them and are “dissimilar” to the objects belonging to other clusters.Fig.3 shows the difference between clustering and unclustering.

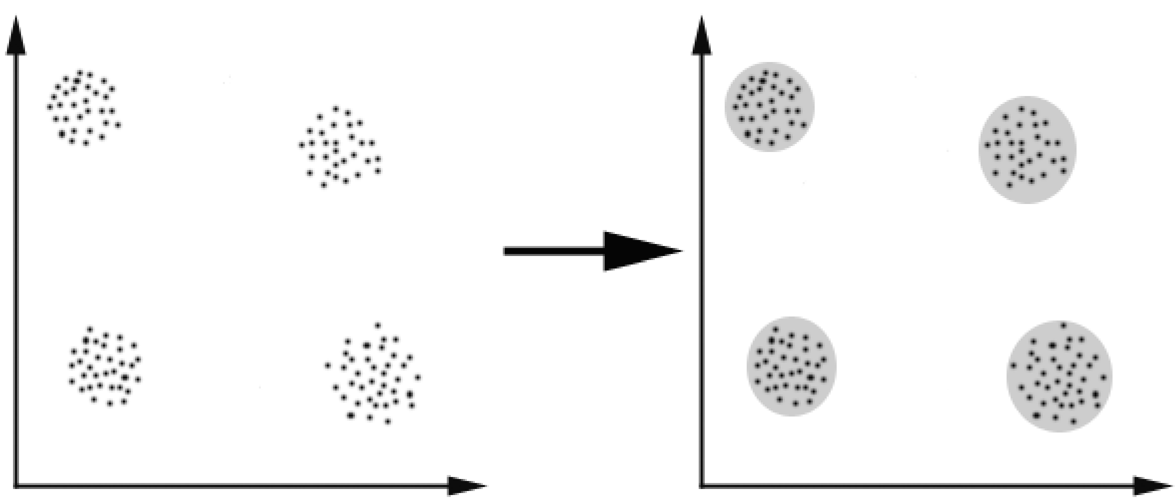


Fig.3.Clustering vs Unclustering

5. THE GOALS OF CLUSTERING

The goal of clustering is to determine the intrinsic grouping in a set of unlabeled data. But how to decide what constitutes a good clustering? It can be shown that there is no absolute “best” criterion which would be independent of the final aim of the clustering. Consequently, it is the user which must supply this criterion, in such a way that the result of the clustering will suit their needs.

For instance, we could be interested in finding representatives for homogeneous groups (data reduction), in finding “natural clusters” and describe their unknown properties (“natural” data types), in finding useful and suitable groupings (“useful” data classes) or in finding unusual data objects (outlier detection).

Applications

Clustering algorithms can be applied in many fields, for instance:

- Marketing: finding groups of customers with similar behavior given a large database of customer data containing their properties and past buying records;
- Biology: classification of plants and animals given their features;
- Libraries: book ordering;
- Insurance: identifying groups of motor insurance policy holders with a high average claim cost; identifying frauds;
- City-planning: identifying groups of houses according to their house type, value and geographical location;
- Earthquake studies: clustering observed earthquake epicenters to identify dangerous zones.

6. COMPARISON BETWEEN WSN AND CR NETWORKS

6.1 Wireless sensor networks

A wireless sensor network (WSN) consists of hundreds to thousands of low-power multi-functional sensor nodes, operating in an unattended environment, and having sensing, computation and communication capabilities. The basic components [1] of a node are a sensor unit, an ADC (Analog to Digital Converter), a CPU (Central processing unit), a power unit and a communication unit. Sensor nodes are micro-electro-mechanical systems [2] (MEMS) that produce a measurable response to a change in some physical condition like temperature and pressure.[4] Sensor nodes sense or measure physical data of the area to be monitored. The continual analog signal sensed by the sensors is digitized by an analog-to-digital converter and sent to controllers for further processing. Sensor nodes are of very small size, consume extremely low energy, are operated in high volumetric densities, and can be autonomous and adaptive to the environment[13] [14].

Each sensor node has a certain area of coverage for which it can reliably and accurately report the particular quantity that it is observing. Several sources of power consumption in sensors are: (a) signal sampling and conversion of physical signals to electrical ones; (b) signal conditioning, and (c) analog-to-digital conversion.

There are three categories of sensor nodes:

(i) Passive, Omni Directional Sensors: passive sensor nodes sense the environment without manipulating it by active probing. In this case, the energy is needed only to amplify their analog signals. There is no notion of “direction” in measuring the environment.

(ii) Passive, narrow-beam sensors: these sensors are passive and they are concerned about the direction when sensing the environment.

(iii) Active Sensors: these sensors actively probe the environment [13].

6.2 Applications

The applications for WSNs involve tracking, monitoring and controlling. WSNs are mainly utilized for habitat monitoring, object tracking, nuclear reactor control, fire detection, and traffic monitoring. Area monitoring is a common application of WSNs, in which the WSN is deployed over a region where some incident is to be monitored. For example, a large quantity of sensor nodes could be deployed over a battlefield to detect enemy intrusions instead of using landmines. When the sensors detect the event being monitored (heat, pressure, sound, light, electro-magnetic field, vibration, etc.), the event needs to be reported to one of the base stations, which can than take some appropriate action (e.g., send a message on the internet or to a satellite). Wireless sensor networks are used extensively within the water/wastewater industries. Facilities not wired for power or data transmission can be monitored using industrial wireless I/O devices and sensor nodes powered by solar panels or battery packs. Wireless sensor networks can use a range of sensors to detect the presence of vehicles for vehicles detection. Wireless sensor networks are also used to control the temperature and humidity levels inside commercial greenhouses. When the temperature and humidity drops below specific levels, the greenhouse manager can be notified via e-mail or a cell phone text message, or host systems can trigger misting systems, open vents, turn on fans, or control a wide variety of system responses. Because some wireless sensor networks are easy to install, they are also easy to move when the needs of the application change[13].

7. EXISTING ROUTING PROTOCOLS

7.1. LEACH (Low Energy Adaptive Clustering Hierarchy)

LEACH is a self-organizing, adaptive clustering protocol. It uses randomization for distributing the energy load among the sensors in the network. The following are the assumptions made in the LEACH protocol:

a. All nodes can transmit with enough power to reach the base station.

b. Each node has enough computational power to support different MAC protocols.

c. Nodes located close to each other have correlated data.

According to this protocol, the base station is fixed and located far from the sensor nodes and the nodes are homogeneous and energy constrained. Here, one node called cluster-head (CH) acts as the local base station. LEACH randomly rotates the high-energy cluster-head so that the activities are equally shared among the sensors and the sensors consume battery power equally. LEACH also performs data fusion, i.e. compression of data when data is sent from the clusters to the base station thus reducing energy dissipation and enhancing system lifetime.[5] LEACH divides the total operation into rounds—each round consisting of two phases: set-up phase and steady phase.

In the set-up phase, clusters are formed and a CH is selected for each cluster. The CH is selected from the sensor nodes at a time with a certain probability. Each node generates a random number from 0 to 1. If this number is lower than the threshold node [T(n)] then this particular node becomes a CH. Then the CH allocates time slots to nodes within its cluster. LEACH clustering is shown in Figure 4.

In steady state phase, nodes send data to their CH during their allocated time slot using TDMA. When the cluster head gets data from its cluster, it aggregates the data and sends the compressed data to the BS. Since the BS is far away from the CH, it needs high energy for transmitting the data. This affects only the nodes which are CHs and that's why the selection of a CH depends on the remaining energy of that node.[5]

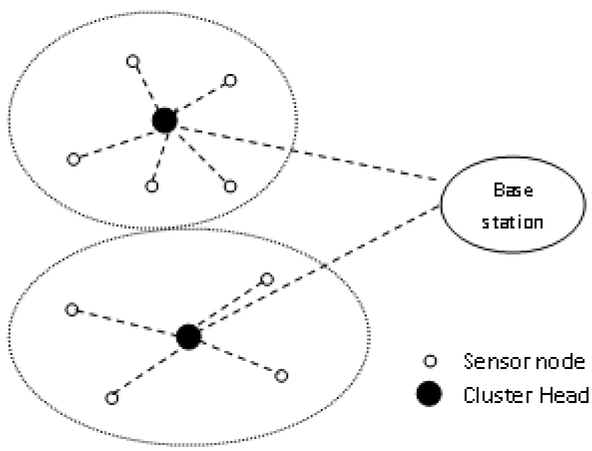


Figure 4. Clustering in LEACH Protocol.

7.2.TEEN (Threshold sensitive Energy Efficient sensor Network)

TEEN is a cluster based hierarchical routing protocol based on LEACH. This protocol is used for time-critical applications. It has two assumptions:

- The BS and the sensor nodes have same initial energy
- The BS can transmit data to all nodes in the network directly.

In this protocol, nodes sense the medium continuously, but the data transmission is done less frequently. The network consists of simple nodes, first-level cluster heads and second-level cluster heads. TEEN uses LEACH's strategy to form cluster. First level CHs are formed away from the BS and second level cluster heads are formed near to the BS. A CH sends two types of data to its neighbors—one is the hard threshold (HT) and other is soft threshold (ST). In the hard threshold, the nodes transmit data if the sensed attribute is in the range of interest and thus it reduces the number of transmissions.[6] On the other hand, in soft threshold mode, any small change in the value of the sensed attribute is transmitted. The nodes sense their environment continuously and store the sensed value for transmission.

Thereafter the node transmits the sensed value if one of the following conditions satisfied:

a. Sensed value > hard threshold (HT).

b. Sensed value ~ hard threshold >= soft threshold (ST).

TEEN has the following drawbacks:

- A node may wait for their time slot for data transmission. Again time slot may be wasted if a node has no data for transmission.
- Cluster heads always wait for data from nodes by keeping its transmitter on[5-6].

7.3. APTEEN (Adaptive Threshold TEEN)

APTEEN is an improved version of TEEN which has all the features of TEEN. It was developed for hybrid networks and captures both periodic data collection and reacts to time critical events.[6-7]

APTEEN supports queries like:

- Historical analysis of past data values
- A snapshot of the current network view.
- Persistent monitoring of an event for a period of time.

In each round, after deciding the cluster head, the cluster head broadcasts the following parameters:

- Attributes (interested physical parameters),
- Thresholds (hard threshold value and soft threshold value),
- time schedule (time slot using TDMA) and
- count time (maximum time period between two successive reports sent by a node).

It allows the user to set threshold values and also a count time interval. If a node does not send data for a time period equal to the count time, it is forced to sense and retransmit the data thus maintaining energy consumption. Since it is a hybrid protocol, it can emulate a proactive network or a reactive network depending on the count time and threshold value. Figure .5 shows TEEN and APTEEN. It has the disadvantage that additional complexity is required to implement the threshold function and count time features.

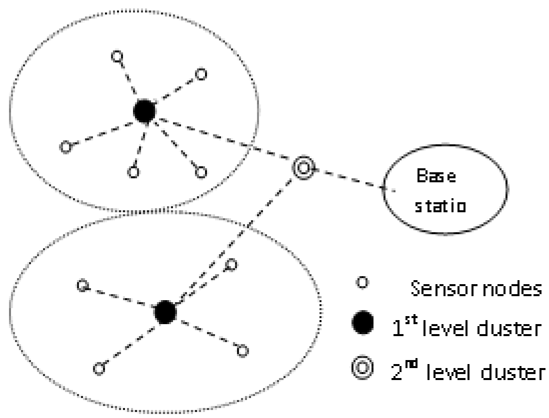


Figure 5. Hierarchical clustering in TEEN and APTEEN Protocols.

7.4. PEGASIS (Power efficient Gathering Sensor Information System)

PEGASIS is a near optimal chain-based power efficient protocol based on LEACH. According to this protocol, all the nodes have information about all other nodes and each has the capability of transmitting data to the base station directly. PEGASIS assumes that all the sensor nodes have the same level of energy and they are likely to die at the same time. Since all nodes are immobile and have global knowledge of the network, the chain can be constructed easily by using greedy algorithm. [9]Chain creation is started at a node far from BS. Each node transmits and receives data from only one closest node of its neighbors. To locate the closest neighbor node, each node uses the signal strength to measure the distance from the neighbors and then adjusts the signal strength so the only one node cab is heard. Node passes token through the chain to leader from both sides. Each node fuses the received data with their own data at the time of constructing the chain. In each round, a randomly [8] chosen node (leader) from the chain will transmit the aggregated data to the BS.

Node i (mod N) is the leader in round i. The chain consists of those nodes that are closest to each other and form a path to the base station. The aggregated data is sent to the base station by the leader. PEGASIS outperforms LEACH by eliminating the overhead of dynamic cluster information, minimizes the sum of distances and limits the number of transmission. Each node requires global information about the network. This is a drawback of this protocol because at any time it can be collected from the network. PEGASIS is shown in Figure. 6[9][10].

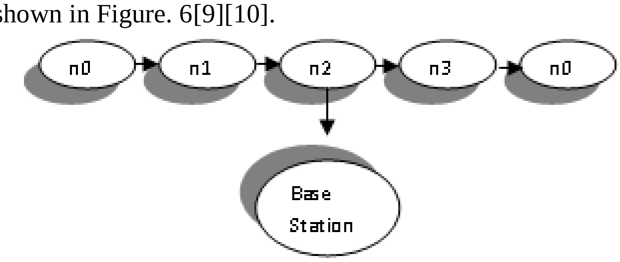
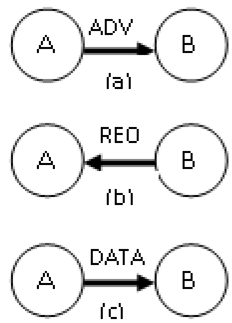


Figure 6. Chaining in PEGASIS.

7.5. SPIN (Sensor Protocols for Information via Negotiation)
SPIN is a family of adaptive protocols that use data negotiation and resource-adaptive algorithms. SPIN is a data centric routing protocol[9][10].
It assumes:
a. all nodes in the network are base stations.
b. nodes in close proximity have similar data.
The key idea behind SPIN is to name the data using high-level descriptors or meta-data. Since all nodes can be assumed as base stations all information is broadcasted to each node in the network. So user can query to any node and can get the information immediately. Nodes in this network use a high level name to describe their collected data called meta-data.
Figure 7 shows how SPIN works.



(a) node A sends ADV message to node
(b) node B sends REQ message to node
(c) node A sends DATA to node B

Figure 7. Data Transmission in SPIN.

Before transmission, meta-data are exchanged among sensors nodes (meta-data negotiation) via a data advertisement procedure, thus avoiding transmission of redundant data in the network. After receiving the data each node advertises it to its neighbors and interested neighbors get this data by sending a request message. The format of this meta-data is not specified in SPIN and it depends on the used applications. This meta-data negotiation solves the classic problem of flooding and thus it achieves energy efficiency. SPIN uses three types of messages: ADV, REQ, and DATA for communication with each other. ADV is used for adverting new data, REQ is used for requesting for data and DATA is the actual message. According to this protocol first a node gets some new data and the node wants to distribute that data throughout the network, so it broadcasts an ADV message containing meta-data. The interested nodes request that data by sending a REQ message and the data is
sent to the requesting nodes. The neighboring node repeats this process until the entire network gets the new data[9]. The SPIN protocols include many other protocols. The main two protocols are SPIN-1 and SPIN-2. These two protocols incorporate negotiation before transmitting data so that only useful information will be transferred. Each node has its own resource manager that keeps track of resource consumption. The SPIN-1 protocol is a 3-stage protocol, as described above. SPIN-2 is an extension of SPIN-1, which incorporates threshold-based resource awareness mechanism in addition to negotiation. When energy
in the nodes is abundant, SPIN-2 communicates using the 3-stage protocol of SPIN-1.
One of the advantages of SPIN is that topological changes are localized since each node only needs to know its single-hop neighbors[11]. SPIN provides much more energy savings than flooding and meta-data negotiation almost halves the redundant data. However, SPINs data advertisement mechanism cannot guarantee the delivery of data. To see this, consider the application of intrusion detection where data should be reliably reported over periodic intervals and assume that nodes interested in the data are located far away from the source node and the nodes between source and destination nodes are not interested in that data, such data will not be delivered to the destination at all.

7.6.DD (Directed Diffusion)
Directed diffusion is a data-centric (DC) and application-aware protocol in which data
generated by sensor nodes is named by attribute-value pairs.
It consists of four elements:

- Interests,
- Data messages,
- Gradients and
- Reinforcements.

An interest (a list of attribute value pairs) describes a task. Data messages are named using attribute value pairs. A gradient specifies data rate as well as the direction of event and reinforcement selects a particular path from a number of paths[10].

In the DC protocol data coming from different sources are combined and thus eliminating redundancy, minimizing the number of transmissions, saving network energy and prolonging its lifetime. DC routing searches for a destination from multiple sources. In directed diffusion, a base station diffuses a query towards nodes in the interested region. The query or interest is diffused through the network hop-by-hop. Each sensor receives the interest and sets up a gradient toward the sensor nodes from which it receives the interest. This process continues until gradients are set up from the sources back to the BS. The sensed data are then returned to the BS along that reverse path. The intermediate nodes may aggregate their data depending on the data message (data's name and attribute value pair) thus reducing the communication cost. Since in this case data transmission is not reliable the BS periodically refreshes and resends the interest when it starts to receive data from the source(s).
Directed Diffusion protocols are application specific and hence can save energy by selecting optimal paths by caching and processing data in the network[11].
It has some drawbacks:
First of all, for data aggregation it needs time synchronization technique that is not very easy to achieve in WSNs. Another problem is associated with the overhead involved in recording information thus increasing the cost of a sensor node. The DD Protocol is described in Figure 8.

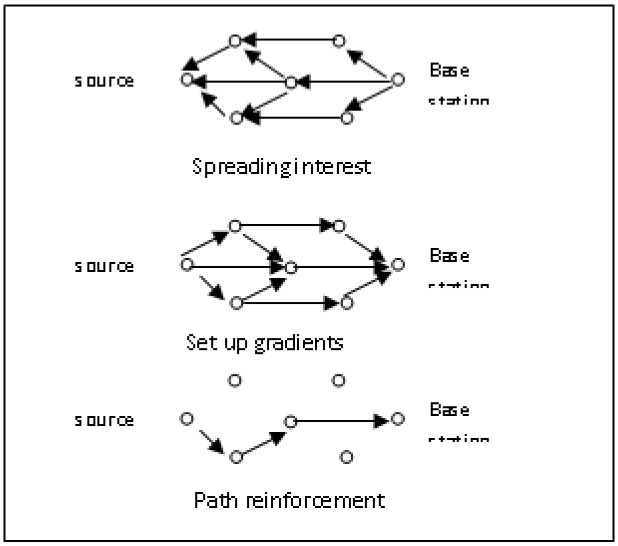


Figure 8. Directed Diffusion Protocol.

7.7. Rumor Routing
Rumor routing is a kind of directed diffusion and is used for applications where geographic routing is not feasible[9] [10]. It combines query flooding and event flooding protocols in a random way. It has the following assumptions:
- The network is composed of densely distributed nodes.
- Only bi-directional links exits.
- Only short distance transmissions are allowed.
- It has fixed infrastructure.

In case of directed diffusion flooding is used to inject the query to the entire network. Sometimes the requested data from the nodes are very small and thus the flooding is unnecessary, so we can use another approach which is to flood the events when the number of events is small and the number of queries is large. The queries are rooted to that particular nodes that are belongs to the interested region.
In order to flood events through the network, the rumor routing algorithm employs long-lived packets, called agents. When a node detects an event, it adds such event to its local table (events table), and generates an agent. Agents travel the network on a random path with related event information. Then the visited nodes form a gradient towards the event. When a node needs to initiate a query, it routes the query to the initial source. If it gets some nodes lying on the gradient before its TTL expires, it will be routed to the event, else the node may need to retransmit, give up or flood the query. Unlike directed diffusion, where data can be routed through multiple paths at low rates, Rumor routing only maintains one path between source and destination. Rumor routing performs well only when the number of events is small. For a large number of events, the cost of maintaining agents and event-tables in each node becomes infeasible if there is not enough interest in these events from the BS.
Moreover, the overhead associated with rumor routing is controlled by different parameters used in the algorithm such as time-to-live (TTL) pertaining to queries and agents
.

7.8. Geographic and Energy-Aware Routing (GEAR)

Location based routing protocols for sensor network need location information of all the sensornodes to calculate the distance between any two nodes. GEAR is a location based routing protocol which uses GIS (Geographical Information System) to find the location of sensor nodes in the network. According to this protocol, each node stores two types of cost of reaching the destination: estimated cost and learning cost. The estimated cost is a combination of residual energy and distance to destination. The learned cost is a modified estimated cost and it accounts the routing around holes in the network. When a node does not have any closure neighbours towards the target region, a hole occurs. In case where no holes exit, the estimated cost is equal to the learned cost[10][11].

The GEAR protocol only considers a certain region rather than sending the interests to the whole network as happens in Directed Diffusion and thus restricting the number of interests.

There are two phases in this protocol:

Phase-I: In this phase, packets are forwarded towards the target region. After receiving a packet, a node searches for a neighbor which is closer to the target region then itself. The neighbor is then selected as the next hop. If there are more than one suitable nodes then there exists a hole and in this case one node is picked to forward the packet based on the learning cost function.

Phase-II: In this phase, the packets are forwarded within the region. If the packet reaches the region, it is diffused in that region by either recursive geographic forwarding or restricted flooding. If the sensors are not densely deployed, then restricted flooding is used and if the node density is high, then geographic flooding is used. In geographic flooding, the region is divided into four sub regions and four copies of the packet are created. This process continues until the regions with only one node are left.

7.9. Geographic Adaptive Fidelity (GAF)

GAF is an energy efficient location-based routing protocol. This protocol was initially conceived for mobile ad hoc networks, but it can also be applied to sensor networks. GAF can be implemented both for non-mobile and mobile nodes. Although GAF is a location based protocol, it may also be implemented as a hierarchical protocol where the clusters are based on geographic location. Initially the area of interest is split into some fixed zones forming a virtual grid for the covered area. Nodes in each zone have different functionalities and each node uses its GPS-indicated location to associate itself with a point in the grid[11] [12].

Nodes which are positioned at the same point on the grid are considered equivalent in terms of the cost of packet routing. Such equivalence is exploited in keeping some nodes located in a particular grid area in a sleeping state in order to save energy. Thus GAF can increase the network lifetime as the number of nodes increases. GAF conserves energy by turning off unnecessary nodes in the network without affecting the level of routing fidelity. GAF defines three states: discovery, active, sleep. The 'discovery' state is used for determining the neighbors in the grid; the 'active' state participates in routing process and at the time of 'sleep' state, the radio is turned off. In order to handle the mobility, each node in the grid estimates it's leaving time of grid and sends this to its neighbors. The sleeping neighbors adjust their sleeping time accordingly in order to keep the routing fidelity. Before the leaving time of the active node expires, sleeping nodes wake up and one of them becomes active.

8. CONCLUSION

The cognitive radio approach promotes a technology as well as changes in radio regulation to overcome the existing barrier. Cognitive radios improve the efficiency of spectrum utilisation. They typically operate at frequencies that were originally licensed to other (incumbent, primary) radio services, and in addition at available frequencies in unlicensed bands[13]. A cognitive radio, however, is not necessarily restricted to the existing licensing for primary radio systems, and operates at any unused frequency, whether or not the frequency is assigned to licensed, primary services. This is referred to as overlay sharing, which obviously requires new protocols and algorithms for spectrum sharing[14]. It also involves important regulatory aspects: Cognitive radios must not interfere with the operation of licensed radio systems when identifying spectrum opportunities and during operation in licensed spectrum[15]. This is explained in more detail in the following paragraphs, where we discuss enabling technologies and trends, and required changes in spectrum regulation.

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