Cognitive Wireless Sensor Network Merits, Applications, Practical Difficulties and Research Trends

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I. INTRODUCTION

Wireless sensor network (WSN) includes a massive number of sensor nodes which performs sensing, processing and observing physical parameters in a distributed manner. The sensor nodes gather fixed data like temperature, acoustics, pressure, gas level, movement, and so to observe the environment for daily activities as well as military purposes [1]. Presently, classical sensor node in WSN simply observes the physical parameters from the environment. Few modified versions of WSN are as cognitive-WSN (C-WSN) [2], wireless multimedia sensor network (WMSN) wireless actor network (WAN), and cryptography in WSN [3] needs to execute algorithm in the nodes itself, however, resource limitations of the sensors in WSN poses a main difficulty. Hence, many of the effective or highly efficient methods like spectrum sensing approaches (C-WSN), image compression and steganography approaches or traditional cryptographic methods are not developed particularly for WSN since they exploit massive amount of resources. In addition, there is no existence or entire ser of conditions to validate the suitability of the algorithm for the recently proposed sensors with classical implicit requirements like compact and inexpensive. For instance, [4] presented various effective methods for spectrum sensing in C-WSN with no logical validation of their choice. A collection of likelihood criterion and a validation approach along with traditional evaluation measures should be proposed to validate methods which are presented for the modified versions of WSN. Alternatively, it can be said that the evaluation parameter of the techniques should include new measures to validate the suitability to implement and execute in the new generations of WSN.

Due to the advancements in the mobile communication, the available frequency spectrum for wireless communication is exhausting and almost complete spectrum is used at some space-time point. [5] presented a method called cognitive radio (CR) approach that enhances the effective usage of the available spectrum. In CWSN, secondary users (SUs) sense the medium to identify the presence of unused frequency bands by licensed users called primary users (PU). Next, SU make use of the available frequency bands for transmitting as well as receiving data. Hence, the identification of the available frequency band in the nearby area of SU is the main idea and purpose in CR, indicating spectrum sensing (SS). SS take place in a centralized as well as distributed way. In a centralized way, every SU sense the frequencies and make a decision among them. In a distributed way, many SUs share the local sensing data to attain reliability and enhanced sensing performance. Presently, CR is mainly assumed as a major portion in the next generation networks. The different between WSN and CWSN is shown in Fig. 1. From the figure, it is clearly exhibited that the CWSN has an additional SS operation in which the WSN has no SS operations.

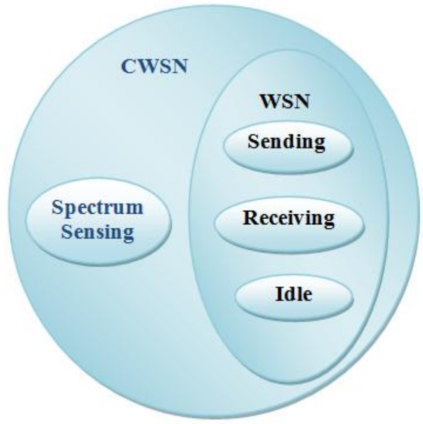

Fig. 1: WSN Vs CWSN

In recent days, CWSN has emerged as a new technology that has been the era of high demand of cognitive networking, where the researchers concentrate on the earlier levels of development. In reality, actual WSN face various issues leads from the constrained bandwidth allocated to them that are normally unlicensed bands. Hence, the use of CR method, new era of CWSN has introduced. It enhances the results in the deployment of WSN application because of the following benefits: has been proposed in the literature. C-WSN improves network performance in WSN applications, due to advantages such as follows [6]:

- Effective Spectrum usage
- Effective Transmission Quality
- High Communication range
- Low node count
- Low Energy utilization
- Maximum Network Lifetime

CWSN comprises of several number of compact and cheap sensor nodes that are constrained by resources as shown in Fig. 2.

Manuscript received February 01, 2019

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The nodes simply transmit and receive the data or in the idle state as well as sensing state. The sensor nodes sense the intended area and transmit the data to base station (BS).

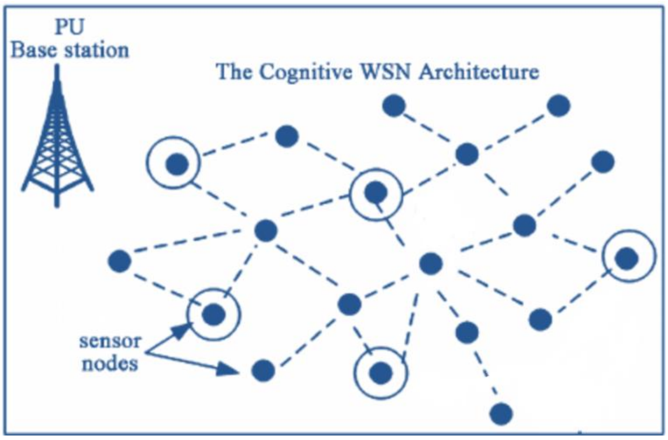

Fig. 2: Architecture of CWSN

II. Potential Application Areas of CWSN

CWSN might comprise of huge application ranges. In the WSN ranges, CWSN might be placed anywhere. Few instances of potential field where CWSN might be placed are give below: maintenance and actuation of complex systems, precision agriculture, logistics, telemetries, facility management, security, monitoring outdoor and indoor fields, preventive maintenance, object tracking, intelligent roadside, machine surveillance, health and medicine. This part describes few interesting domains where CWSN might be placed with instances.

2.1. Military and Public Security Applications

In numerous public security and military applications, traditional WSNs are employed, like (a) nuclear attack detection, chemical biological radiological and investigation; (b) battle damage examination and collecting the data; (c) intelligence assistant (d) targeting, (e) battlefield surveillance; (f) command control; and so on. To disturb radio communication channels [7], jamming signals are sent by an adversary in dispute areas or battlefield. As CWSN can employ various frequency bands, and over a vast range, sensor nodes can handoff frequencies in these circumstance; hence with a jamming signal, preventing the frequency band. Reduced channel access, delay in communication and huge bandwidth are needed by few military applications additionally. CWSN might be a good choice for those applications.

2.2. Health Care

Wearable body sensors and telemedicine are employed highly in health care machines. Over patients, many WSNs are placed and through health care providers, attaining critical data for remote monitoring. A benchmark for technology of body area network (BAN) has been approved by IEEE 802.15 Task Group 6 in 2011. In few remote regions of some countries like India and Nepal which are under developing country, these Wireless BAN-assisted health care systems are in practice already. It is appropriate when the physicians are comparatively low. Medical information is error sensible, delay and critical. Hence, in last part, the conventional WSNs limitations have been discussed. When the operating spectrum band has been jammed in suitable 'telemedicine with BAN', QoS would not attain in a sufficient level. Because of the global operability, bandwidth, and jamming, the implication of 'CR wearable body wireless sensors' can reduce the issues and enhances the trustworthiness. A design has been presented in Fig. 3, for wireless BAN along with CR wireless sensors. In WBASN domain, an appropriate researched had been performed. In [8], in wireless medical networks, the need of cognitive radio implementation is discussed.

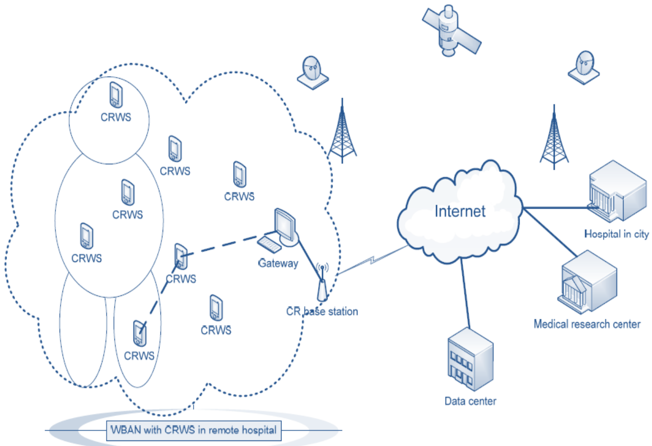

Fig. 3: CWSN in hospital scenario

2.3. Home Appliances and Indoor Applications

To attain sufficient QoS, numerous indoor and potential applications need a WSN environment which is dense can be implicated. In attaining trustworthy communication, traditional WSN suffers potential difficulties as the ISM bands are highly jammed in indoor areas. Factory automation, personal entertainment, intelligent buildings and home monitoring systems are few WSN indoor application examples. The difficulties that are faced through the traditional WSN in indoor applications can be reduced through CWSN.

2.4. Bandwidth-Intensive Applications

Due to the high requirements of bandwidth, multimedia applications like audio, video streaming and pictures are highly challenging over resource limited WSNs. In data density related with node density, other applications of WSN like, surveillance, vehicular WSNs, hospital environment, tracking and so on., comprise extensive temporal and spatial modifications. The applications are bursty, intolerable by means of delay and bandwidth-starving. SU might acquire several channels wherever necessary and available as in CWSN, for these bandwidth-starving application kinds, CWSN is highly appropriate. For those applications that are bandwidth intent, Rehmani et al. [9] suggested channel bonding in CWSNs.

2.5. Real-Time Surveillance Applications

Practical application that are placed in surveillance like environmental monitoring, biodiversity mapping, traffic monitoring, habitat monitoring, weather monitoring which affect crops, underwater WSNs, livestock and crops, vehicle tracking, disaster relief operations, tunnel

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monitoring, bridge monitoring and need reduced communication delay and channel access. Few practical monitoring applications need enhanced trustworthiness and they are extremely delay-sensitive. When the condition of the channel is not of high quality in multihop WSNs, a delay in order to a link failure might happen. When better conditional idle channel is found in CWSN, it hops to that node. To enhance the channel bandwidth, implication of numerous channels simultaneously and aggregation of channel are probable in CWSN.

2.6. Transportation and Vehicular Networks

For wireless access in vehicular environments (WAVE), the standard of IEEE 1609.4 projects multi-channel operations are done. With six service channels and one control channel, the WAVE can work over 75 MHz spectrum in 5.9 GHz band. The entire vehicular consumer would run for accessing the channel and to send data in 5.9 GHz band. But, it has to face the problem of spectrum insufficiency. In [10], the problem of spectrum scarcity and cognitive radio need in WAVE has been presented. Few studies in CR-enabled vehicular communications had been performed [11]. In urban situations, vehicular WSN are rising as a novel network framework for collecting surveillance data proactively. In this domain, CWSN are related highly. Few conventions for highway safety had been projected using CWSN, this domain requires to be analyzed.

2.7. Diverse Purpose Sensing

The implication of wireless sensors in similar domain for various goals present highly. The wireless sensors in traditional WSN try to acquire the channel in non-cooperative way. CWSN may choose various channels for various applications assuming fairness and load balancing with the support of medium access control (MAC) protocol that is efficient.

III. Advantages of Using CR in WSNS

In the field of sensor networks, CWSN is a novel framework which uses effectively the spectrum resource for burst traffic. The frameworks comprise the ability like enhanced communication quality, power waste, reduction in packet loss and enhanced buffer management. The benefits of cognitive radio in WSN are discussed here.

3.1. Efficient Spectrum Utilization and Spaces for New Technologies

The electromagnetic spectrum is superior by nature. The sum of implementable spectrum bands that are available cannot be enhanced however they might be employed highly. To use the radio bands, one individual needs a government license of that country with the scientific and medical (ISM) radio bands and industrial exception. Over constructing devices for ISM bands, numerous researchers and hardware manufacturers have aimed due to the elevated cost linked with spectrum licensing. Hence, constraining the novel methods, ISM bands are jammed. At the same time, numerous spectrum bands which is licensed are highly unused or underused. Instead of license holder disturbance, Cognitive radio wireless sensors can employ the unused spectrum known as white spaces. Unlicensed consumers might band with no cost or with little as high methods can be built for bands. As described through ITU-R,

3.2. Multiple Channels Utilization

Single channel can be used by highly conventional WSNs. Sensor node produces the packet bursts jam in WSN, over the event detection. On the other hand, a huge count of WSNs in highly placed WSN, with the region of event tries to access the similar channel. Because of the losses in packet, this enhances the collision probability and reduces the entire communication trust that tends to high packet delay and power utilization. To improve this possible difficulty, opportunistically CWSN can acquire numerous channels.

3.3. Energy Efficiency

Because of the loss in packet, there exists a huge energy waste for retransmission of packet in WSN. To adjust the condition of channel, CR wireless sensors may capable to modify its operating attributes. Hence, energy utilization because of the retransmission and collision of a packet can be reduced.

3.4. Global Operability

Spectrum regulation conventions are framed by every country. A particular band in one countryside may not be allowable in other. Conventional wireless sensors with predetermined work frequency may be performed in situations like wireless sensors are placed in various areas. At the same time, it can avoid the issue of spectrum incompatibility through modifying its communication frequency band if the nodes contain cognitive radio ability. Hence, CR wireless sensors can be used over the world.

3.5. Application Specific

Wireless sensors placed for various applications has enhanced nowadays, with the Spectrum Band Utilization. Both spatially and temporally, data congestion is always related in WSN. It is probable wireless sensors placed for similar idea employs the various incumbents spectrum in spatial overlapping areas with the intelligent communication protocols in CWSN. With supportive communication over SU, this is probable that reduces interference problems.

3.6. Financial Advantages to the Incumbents by Renting or Leasing

When few licensed spectrum bands are not needed, the license holders might lease their spectrum to the SU at low cost. This might be performed when regaining the incumbent access over spectrum bands if required. This is a good chance for an individual who cannot get a straight license for a particular spectrum because of the financial and legal problems. This is a good method for SU and incumbents.

3.7. Avoiding Attacks

Most of the wireless sensors work over certain frequency bands unlike sensor nodes in CWSN. SU which resides in CWSN can prevent many attack kinds, extensive spectrum usability as an advantage.

IV. Practical Difficulties in CWSN

CWSN vary from traditional WSN in various dimensions. Due to the process of safeguarding the rights of PUs in CWSN, many practical difficulties arose in traditional WSN.

4.1. Detection, False Alarm, and Miss-Detection Probability

The detection probability is a measure employed to detect correctly with respect to the non-existence of PU in the channel. The miss-detection probability is a measure detects the existence of primary signal on the channel, and the false-alarm probability is a measure fails to identify the sensor node which fails to identify the non-existence of the primary signal. A false alarm leads to non-usage of available spectrum efficiently and the miss detection leads to interference with the PUs. Additionally, the false alarm and miss detection leads to high delay, often switching between frequencies and low throughput. This problem has to be studied well to satisfy the needs of CWSN.

4.2. Hardware

The sensor nodes in CWSN have limited resources interms of processing, memory and power supply. Opposite to traditional wireless sensor nodes, it has the ability to sense the channels, investigate and decide. The sensor nodes have the capability to modify the parameter or transmitter with respect to the interaction with the physical world. The architecture of a sensor node in CWSN has 6 main components as shown in Fig. 4: sensing unit, processing and storage unit, CR unit, communication unit, power supply and miscellaneous unit. The sensing unit has actual sensors and analog to digital converter (ADC). The analog signals captured by the sensor are transformed to digital data and is process by the processing unit. The CR unit has the cognitive ability and it requires adapting with the transmission variables like carrier frequency, transmission power, and modulation. The CR unit requires choosing the optimum channel, handling the movement of spectrum and so on. The communication unit has the responsibility of transmitting and receiving data. The design of intelligent hardware in CWSN is a difficult process. Several artificial intelligence methods have been presented to satisfy the fundamental concept of CR.

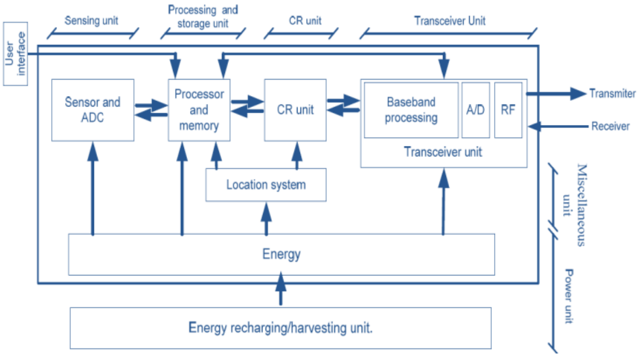

Fig. 4: Structure of a sensor node in CWSN

4.3. Topology modifications

Topology straightly influences the network lifetime in CWSN. Based on the application nature, sensor nodes undergo deployment in a static or dynamic manner. In most of the cases, the node failure in CWSN exists because of hardware failure of energy exhaustion. The topologies of the CWSN and WSN are same. An adaptable self-configuration topology is essential for CWSN to obtain scalable, reduced energy utilization and achieve better results. The dynamic self-configuration topology offers static topology, even though it is a demanding problem to design and implement. This field needs to be explored more.

4.4. Fault Tolerant

The CWSN should have autonomous, self configure and self-healing capabilities. It can be stated as, when the link failure occurs, a substitute path will be derived that eliminates the presence of fault nodes. There are various ways to make the node faults like hardware or software not working, or natural calamity, and so on. The nodes in CWSN should deal with these scenarios. Various types of faults exist namely node fault, network fault, and sink fault, etc. [12] defined the fault tolerance or reliability Rk(t) of a node by the use of Poisson distribution in the time interval (0,t) as follows:

$$R_k(t) = \exp(-\lambda_k t) \qquad (1)$$

where λ_k is the failure rate of wireless sensor node k and t is the time period. The fault tolerance is a main issue in CWSN and techniques need to be developed should be fault tolerant.

4.5. Installation Cost

In general, many sensor nodes are deployed in the CWSN to cover the intended region. So, the installation cost should be low. Contrasting to traditional WSN, it needs low storage space and processing abilities. For minimizing the hardware cost, the techniques developing for CWSN should operate with minimum storage and processing abilities. In addition, the use of intelligent radio, application specific positioning systems (e.g., GPS), energy harvesting unit and so on enhances the installation cost.

4.7. Channel Selection

In CWSN, as there exists no devoted channel to transmit data, with the neighbors, the sensors require to settle and choose a channel for data communication. As there exists no collaboration among SU and PU, this is difficult problem. At any time, PU might arise at channels. The SU tends to leave out of the channel at that time when PU claims for the channel. Assuming the PU behavior over the channel and employing few AI methods, data channels should be chosen wisely.

4.8. Scalability

In larger counts, the CR wireless sensors should be place for few applications. For spectrum data sharing, CR wireless sensors need collaborations over nodes unlike traditional WSN nodes.

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For CR wireless sensor with heterogeneous environment, it is very complex to coordinate. Because of the increasing network size, protocols and method built for CWSN must be able to resolve the problems.

4.9. Power Consumption

With a constrained energy source, CR wireless sensors are energy limited devices. Power required for reception and transmission of data packets, data processing, spectrum sensing, route discovery, back off, channel negotiation, in addition to all of the above, CR wireless sensors need power for frequent spectrum handoff. A CR wireless sensor requires to intellect PU action over the channel. To PU action monitoring, numerous applications need numerous antennas, therefore high power is utilized. For energy retrieval, there exist many researches, and these methods comprise its own disadvantages. Replacing the energy resources or energy retrieval is not probable in few applications. In [13], those disadvantages are given. Power utilization is not a significant consideration in ad hoc CRNs, however it is an significant design factor. But, it is one among the major performance measure in CWSN which straightly affects network lifespan.

4.10. Quality of Service (QoS)

The QoS is commonly divided through four attributes in traditional WSNs: jitter, bandwidth, reliability and delay. WSN requires managing a sufficient QoS level in order to prevent risky consequences in significant applications. In WSN, memory, power resources and processing power are the resource limitations which the QoS support is a difficult problem. It also suffers from other problem like preserve the PU rights to acquire incumbent spectra. With SU, PU communication shall be interference free. This is highly difficult that it is complex to PU arrival prediction over the channel. False alarm and primary signal miss-detection can add extra difficulty.

4.11. Security

In an unattended environment, the wireless sensors are generally placed and are highly probable to have the problems like privacy and security. Physically, the CR wireless sensors can be attacked in addition the data might get stolen. When compared to traditional WSN, CWSN are prone to security threats, as there exist no collaboration among SU and PU communication. Through unauthorized entities, the data gathered through CR wireless sensors can be destroyed, modified or sniffed. Through SU via spectrum sensing data falsification (SSDF), attacker can hinder with PUs transmission or avoid the channel implications. Over the possible attacks and threats, CWSN might comprise few allowed security robustness level. Additional difficulties exist in CWSN, with the traditional WSN security problems.

V. EXPERIMENTAL ANALYSIS AND RESULTS

An experimental analysis is made between two protocols LEACH [14] and TEEN [15] in CWSN environment. OPNET is used for modeling and simulating the network. It makes use of three layer of modeling process: network, node, and process. The simulation parameters are given as follows: a set of 100 nodes and 10 authorized nodes are arbitrarily placed in the CWSN with the area of $500x500m^2$. A total of 5 channels, exist namely, f1, f2,..,f5 and the intial energy is set to 5J and idle channel probability (Pf) = 0.3. BS is located (1000 m, 1000 m) away from the CWSN.

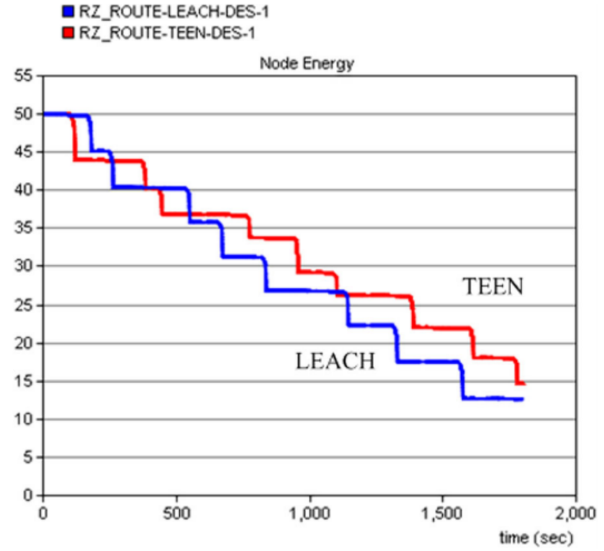

Fig. 5: Energy consumption of single node under TEEN and LEACH

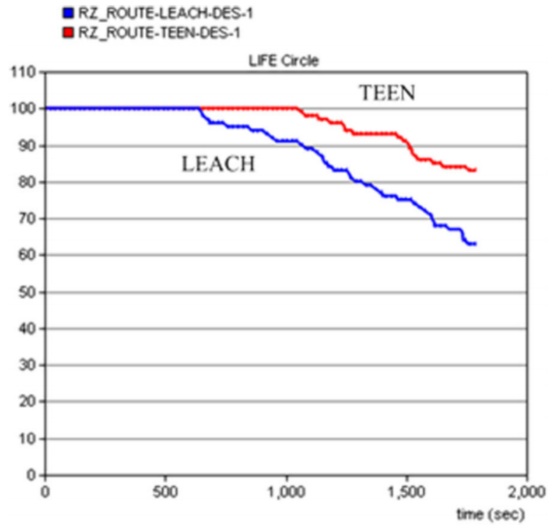

Fig. 6: Life cycle of CWSN by LEACH and TEEN

Once the network is modeled and simulated, selecting one of the cognitive nodes, the energy utilization of LEACH and TEEN routing protocol is depicted in Fig. 5. The graph is plotted between number of several rounds and node energy. The network lifetime of the TEEN and LEACH are compared as provided in Fig. 6. The graph is plotted between number of alive nodes over simulation time. From the Fig., it is clear that the TEEN stays longer than the LEACH protocol. It states that the TEEN has reduced energy utilization compared to LEACH. Fig. 7 illustrates the dead node count by the LEACH and TEEN protocol. From the fig, it is clear that the nodes begin to exhaust complete energy after 600s. But, TEEN lengthens the lifetime and nodes starts to die at 1000s. It is known that TEEN achieved reduced energy utilization and lengthen the lifetime in CWSN compared to LEACH.

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Because of the use of threshold values in TEEN, the number of data transmission is limited.

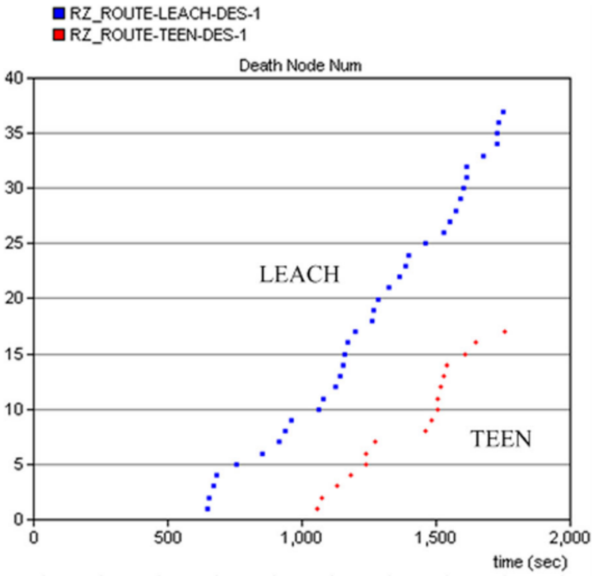

Fig. 7: Comparison of network lifetime by TEEN and LEACH

VI. CONCLUSION

In recent days, CWSN has emerged as a new technology that has been the era of high demand of cognitive networking, where the researchers concentrate on the earlier levels of development. In reality, actual WSN face various issues leads from the constrained bandwidth allocated to them that are normally unlicensed bands. This paper has explored various fundamental concepts, architecture, benefits, applications and practical difficulties in CWSN. This study explains the benefits of CWSN, variation from conventional networks and significant application areas. At the end of the paper, an experimental analysis also takes place. The experimental values stated that TEEN achieved reduced energy utilization and lengthen the lifetime in CWSN compared to LEACH.

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