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Towards Green Computing for Internet of Things: Energy Oriented Path and Message Scheduling Approach

Laith Farhan, Rupak Kharel*, Omprakash Kaiwartya, Mohammed Hammoudeh and Bamidele Adebisi

***Abstract*—Recently, energy efficiency in sensor enabled wireless network domain has witnessed significant attention from both academia and industries. It is an enabling technological advancement towards green computing in Internet of Things (IoT) eventually supporting sensor generated big data processing for smart cities. Related literature on energy efficiency in sensor enabled wireless network environments focuses on one aspects either energy oriented path selection or energy oriented message scheduling. The definition of path also varies in literature without considering links towards energy efficiency. In this context, this paper proposes an energy oriented path selection and message scheduling framework for sensor enabled wireless network environments. The technical novelty focuses on effective cooperation between path selection and message scheduling considering links on path, location of message sender, and number of processor in sensor towards energy efficiency. Specifically, a path selection strategy is developed based on shortest path and less number of links on path (SPLL). The location of message sender, and number of processor in specific sensor are utilized for developing a longer hops (LH) message scheduling approach. A system model is presented based on M/M/1 queuing analysis to showcase the effective cooperation of SPLL and LH towards energy efficiency. Simulation oriented comparative performance evaluation attest the energy efficiency of the proposed framework as compared to the state-of-the-art techniques considering number of energy oriented metrics.**

***Index Terms*—Internet of things (IoT) , energy optimization, wireless sensor networks (WSNs), scheduling algorithm, routing protocol, network lifetime.**

I. Introduction

INTERNET of Things is an emerging heterogeneous networking concept aimed towards a significant impact in the todays digital world. The key vision of IoT is to bring together a massive number of smart objects towards integrated and interconnected heterogeneous networks, making the internet even more ubiquitous. It is a futuristic paradigm where all possible devices will interact with each other regardless of their size, computing resource and network connectivity in a seamless environment. It makes applications smart by sensing, data harnessing, and decision making towards actions mostly without human intervention. IoT-enabled devices are growing with exponential pace including wearable devices, kitchen appliances, connected cars, and healthcare devices [1]. The growth in connected devices is expected to significantly increase over the next few years according to a forecast by the Cisco Systems, "i.e., 10 billion in 2014 to 50 billion by 2020" [2]. Moreover, IoT and other enabling technologies will have significant impact on information gathering on larger geographical area for applications such as, environmental monitoring, healthcare, and surveillance. It is highlighted that a massive number of objects will be enabled with the realization of IoT ecosystem in any geographical area. In such systems, a large number of connected devices will transmit a huge amount of data resulting in the realization of connected device oriented big data. The connected device oriented data is vital for smart city paradigm as it can provide usable knowledge for enabling expert systems in IoT environments [3]. IoT framework is based on several enabling technologies including wireless sensor networks (WSNs), cloud computing, machine learning, and peer to peer systems.

WSNs are one of the key enabling technologies for IoT and will include large number of sensor nodes that are responsible for collecting key information, perform some computation and accomplish wireless communication. These nodes are deployed in a large geographical area and generally configured in a mesh network, ultimately sending a large volume of data to a base station (BS) or a gateway and are usually forwarded with multiple hops to reach the BS [4]. So, in fact energy optimization is not just the problem of the network, it is also one of the greatest challenges for the big data and smart city concept [5, 6]. In an IoT environment, since millions of nodes are interconnected with each other giving rise to big data, one of the key challenge is to make these nodes energy efficient such that the network is able to last longer, otherwise, changing battery to keep collecting the big data will quickly become infeasible. For the WSNs to be energy efficient, the multi hop of the packets i.e. routing protocol plays a significant part [7]. For most of the applications use-cases, the sensor nodes are deployed in inconvenient locations and therefore are difficult to reach. Also, because of the large number of nodes, changing the battery on these nodes regularly is impractical. The majority of the energy consumption on a node occurs during the transmitting and receiving of the data packets, while mostly on other times the node is in inactive or sleeping mode [8]. Since, the battery life

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of any particular node is not infinite, prolonging the network lifetime by reducing the energy consumption and minimizing redundant data transmission during the routing is a key aspect for the overall functioning of the network. Moreover, during multi hop of packets amongst the nodes, the probability of the packet drops increase. This is because of various factors such as packet arrival rate, timeout for message expiry and simply limitations of node due to its constrained nature (low processing, memory and bandwidth resources). Therefore, to avoid packet loss in the network, receipt acknowledgement of transmitted packets or otherwise retransmission of the lost data packets must happen. This will add more load on the already constrained network and contributes further to the power depletion in the nodes.

The sensor enabled wireless network oriented IoT framework can be realized as either application specific smaller network or ecosystem oriented scalable networks. In application specific smaller implementation, packet transmission to the base station is considered within a single or two hops distance [9]. However, in ecosystem oriented scalable implementation, multi-hop communication is considered between source node and base station. The ill impact of multi-hop communication in terms of higher energy requirement worsen in case of transmission between border nodes. The energy wastage in retransmission of the packets and its impact on overall energy consumption must be accounted in the durable network lifetime cum energy efficient implementation of sensor enabled network environments. Here it is worth noting that sensor enabled wireless network environments is the core framework towards realizing IoT environments. Thus, one of the major issue in realizing sensor enabled IoT environments is the limited energy power associated with tiny sensor enabled IoT devices. Recent literature on energy efficiency in wireless network environments focuses on either energy oriented path selection or energy oriented message scheduling. The definition of path also varies in literature without considering number of links towards energy efficiency.

In this context, this paper proposes an energy oriented path selection and message scheduling framework for sensor enabled wireless network environments. The technical novelty focuses on effective cooperation between path selection and message scheduling towards utilizing the benefits of both these techniques. Moreover, the definition of path considerers number of links as major components towards reducing overall energy consumption in data dissemination. The location of message sender, and number of processor in sensor towards energy efficiency. Our contributions in this paper is summarized below:

- An energy oriented path selection strategy is proposed focusing on shortest path and less number of links (SPLL) as major energy consumption parameters.
- The location of message sender, and number of processor in specific sensor are utilized for developing a longer hops (LH) message scheduling approach towards reducing energy consumption in selected path.
- A system model is presented based on M/M/1 queuing analysis to showcase the effective cooperation between SPLL and LH towards energy efficiency.
- Simulation oriented comparative performance evaluation is carried out towards assessing the energy efficiency of the proposed framework as compared to the state-of-the-art techniques considering number of energy oriented metrics.

The remainder of this paper is outlined as follows. Section II critically reviews related literature on energy efficiency in sensor enabled wireless network environments. Section III presents the detail of the proposed energy efficient framework for sensor enabled networks. Simulation oriented comparative performance evaluation is discussed in Section IV, followed by conclusion made in Section V.

II. Related Work

A. Energy Oriented Path Selection

Several energy saving schemes for WSNs have been proposed by various researchers over the last decade or so. Most of the works involved manipulating the location of the sink or implementing the concept of CH within the network [10]. In the work [11], the idea of mobile sink is implemented where it moves in a certain path to collect the data within the network. In such scheme, all the nodes regardless of the length will establish a connection with the sink hence is the limitation since the total link length of the network will be very high. To avoid this, another approach where the network area is divided into multiple clusters and each cluster is assigned with a CH is implemented. In this setup, the CH node is responsible for forwarding all the packets received from non-CH nodes to the base station [12]. The function of non-CH nodes in this setup is just to collect the information and send it to the CH or to another node to form multi-hop. This scheme helped reduce the overall network link length and data transmission distance in the network thus helped to make the network energy efficient as compared with just the mobile sink based WSNs.

Various strategies to choose the CH in the network have been proposed in the literature to optimize the energy usage. Low energy adaptive clustering hierarchy (LEACH) is one of the most popular strategies where the CH is selected based on some probabilistic approach and the amount of energy left and rotated at different time intervals [13]. Nodes that have already been CH cannot be selected again for N rounds where N is the desired predefined percentage. CH will broadcast itself in the network and other non-CH nodes will choose itself to be in the cluster depending on the received strength of the broadcasted message from the CHs so that it requires minimum communication energy. The nodes will be in standby mode except when transmitting to the CHs. The cluster heads will aggregate data from all the nodes, compress it and then forward it to the ultimate receiver. Some more modifications of LEACH are proposed such as LEACH-F and LEACH-C [14]. In LEACH-C, the cluster heads are selected using a central algorithm to form better cluster and in LEACH -F, fixed cluster with rotating CH is adopted. Many variations of LEACH algorithm where different approaches are adopted to form the clusters and select the CH have been reported such as in [16, 17]. The overall goal in all these approaches is to prolong the lifetime of CHs in the sensing field. In HEED (hybrid, energy-efficient and distributed) protocol, cluster heads are formed based on remaining energy on the node taking a probabilistic approach [15]. In super-CH, a fuzzy logic based clustering approach is used by the mobile sink upon receiving information such as remaining battery power, centrality of the cluster, mobility of the BS from the nodes [18] . In [19] and [20], optimal location for the mobile sink was chosen so that the average transmission distance is reduced. A comprehensive survey on the LEACH based algorithm is provided in [21]. Even though LEACH and its derivative algorithms paved way for implementing energy efficient routing protocol, all of them suffer from one fundamental problem. The node that is selected to become CH will die quickly if larger area is to be supported.

Multi-hop clustering approach was proposed in [17]. Here each node, instead of sending the data directly to the CH, will send data via neighbouring nodes forming multiple hops up to the CH. This will shorten the effective data transmission distance between two nodes, thus reducing the energy consumption. The main principle in this modification is to distribute the load amongst all the nodes in the cluster instead of putting entire burden on the CH. In [22], the authors propose a tree based mobile sink (TBMS) and show that the technique performs best when compared to other similar techniques. In this work, a dynamic sorting algorithm for adaptive decision to create the routing structure is proposed. However, this has been implemented on a small number of nodes (100) and smaller sensing area. There is also no guarantee that the mobile sink can reach all the sensors in the sensing field or it might take too long to do so because of the random movements. Therefore, this method may not be fit for purpose for a bigger coverage area and higher number of nodes. Also, if the speed of the MS is too slow, then it will cause packet delay and on contrary if the mobile sink has high speed then it may cause high packets loss.

B. Energy Oriented Message Scheduling

Most of the previous studies do not consider overheads due to retransmission of the packets. For example when a connection oriented protocol is established such as TCP [23] then it uses three way handshakes to establish the connection between the source and destination for reliability. This leads to significant increase in network traffic and thus increases the data volume. Moreover, retransmission data can consume even larger amount of energy due to processing and storage requirements. Therefore, when the techniques are analysed, overhead must be deliberated since retransmission will add burden to the network, reducing the network lifetime. Thus, in order to reduce the power and memory usage, superior routing protocol optimized for these overheads must be developed. In [24], the authors propose and evaluate an energy efficient routing technique called GreeDi algorithm. The proposed scheme focuses on the amount of energy consumed on transporting the information between the user and cloud based on the linear programming approach.

Also in a multi-hop environment, scheduling of the data packets at the node from different neighbouring nodes is also an important aspect for energy efficiency. For example, if the queue is scheduled inefficiently then the packet drop might happen and retransmission will be necessary. The problem is serious for border nodes. Various scheduling algorithms have been proposed to be used in WSNs. In [25] introduced a new scheduling method for nodes located between two coverage areas. This approached is managed to solve the diversified scheduling problem of border nodes in S-MAC and evaluated the performance through simulation [26]. This method has problem of synchronization errors. A message scheduling algorithm that considers node failure in IoT environment is presented in [27]. A message broker is proposed in each cluster that is responsible for sending the messages to the base station on a precise order of delivery by implementing energy efficient shortest processing time (SPT) scheduler. Earliest deadline first (EDF) scheduling algorithm has also been used to manage real-time tasks in the queue in the WSNs where high priority is assigned for packets closest to deadline or expiry [28]. Methods based on EDF are reported by the authors in [29, 30]. Performance analysis of EDF scheduling in multi priority queue is reported in [29]. Similarly, C. Houben et al. [30] have discussed reducing energy consumption in the real time systems by sorting the tasks with enhanced EDF to vary the processor modes determined by supply voltage, frequency and performance requirements. The challenge with EDF does not consider time redundancy management. So, scheduling tasks will complete within them expire times even in the presence of faults. Also, it does not differentiate between packets coming over longer distances and more hops thereby using higher energy.

Methods based on multi-core processor to manage multiple real time tasks have also been used. Dynamic Voltage and Frequency Scaling (DVFS) used low time complexity to avoid the deadlines of the real time tasks and showed that it can minimize up to 64% energy used for each tasks on a separate core [31]. In [32], multi-processor based on ultra-power CoreL and fast CoreH is used. This schedules the tasks between these two processors and runs multi-tasks at the same time. However, the problem with multi-processor system is that it can be expensive and require large memory. Also, overheating after a period of time can cause device damage.

There are many works in the area of IoT and smart cities technology to optimize energy usage by all nodes deployed for creating big data setup. Because if the IoT infrastructure is not optimized then there will be no sustainable big data setup since the nodes start to die quickly. Based on the above discussions and motivations, we propose a power saving scheme that combines efficient routing and scheduling algorithm to reduce the transmission data and thus elongate the network lifetime in a large WSNs and IoT networks.

III. Proposed Power Saving Scheme

In order to reduce the energy consumption, data sent, and thereby extending the lifetime of the sensor nodes deployed in a WSNs for a IoT system, we have developed a power saving scheme that optimizes both the routing and scheduling of the data packets. This reduces the average data transmission distance for all nodes therefore improving on the energy saving to maximize the network lifetime. The adopted scheme reduces the requirement for data retransmission especially for data packets that utilize more energy. Also, this scheme provides better network coverage on a larger area and for large number of nodes that is more consistent to future IoT networks. We have adopted an architecture as in Fig. 1 where clusters are utilized to overcome the limitations of direct links. In each round, the BS receives the position information, number of hops and number of links connect to each sensor node based upon which CH is determined. Multi-hop concept is used to minimize the transmission distance between nodes and to cover wider geographical region. The sensor nodes (SNs) are distributed randomly in the network. SNs are considered as energy constrained whereas the BS is located in fixed position (centre of area) and fully powered. In this scheme, a new routing protocol, SPLL, and a new scheduling algorithm, LH, are proposed.

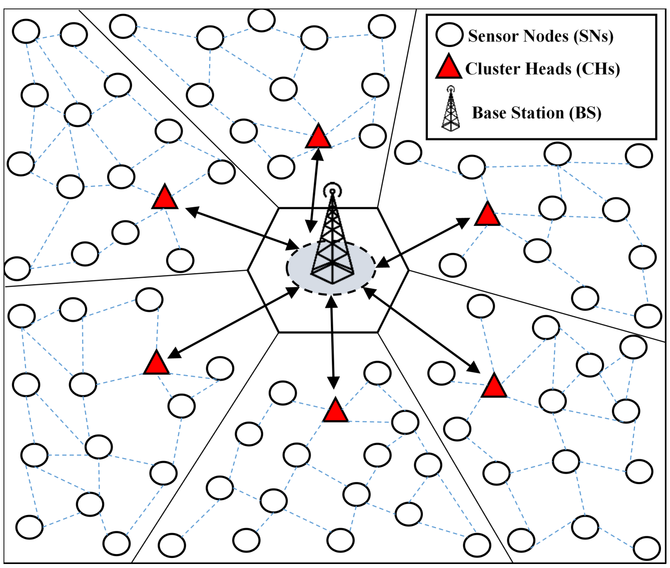

Fig. 1: System architecture.

A. SPLL

Routing strategy is a key functionality for direct and indirect communication over a network. It is used to determine the optimal paths between network nodes based on the routing metrics. Network load balance is the ability to manage the traffic of network links without complex routing policy. Many design goals are related to load balancing such as small delay, energy consumption, high throughput, limited variance of the connection quality. Energy efficiency is a major concern in WSNs and IoT networks because the nodes have restricted battery lifetime. SPLL algorithm manages the data transmission efficiently to minimize the energy consumption and maximize the lifetime of the network.

We assume that all nodes have the same capabilities and include a global position system (GPS) receiver [33]. In order to retrieve the neighbouring nodes for each node and distance from the source node to the BS, a new routing information base (RIB) has been created to store as a data table in the base station. The BS sends Hello Message REQuest (MessREQ) to discover all nodes that belong to it. MessREQ packet includes BS information such as (address, MAC address, position information) that it wants to share with all the SNs. SNs get and store this information and send RESPond (PIRESP) packets back to the BS. However, nodes are in sleep mode if out of coverage area. The BS receives and stores reply request (PIRESP) packets from all sensors belonging to the network. PIRESP packet contains information about the number of nodes linked to each node based on the maximum radio sensing. It also includes the distance from a single node to the BS based on the number of hops and position information. The BS broadcasts this table information to all the CHs and each CH disseminates this information to all the nodes covered by the CH. All SNs now can send the data using the multiple hops based on the routing table. The pseudocode for this routing algorithm is shown in Fig. 2.

Algorithm 1 : Pseudocode for processing advertisement packets and SPLL route

procedure ProcessingAdvertisePackets
    BS sends $Hello\ MessREQ$ to the SNs
    for all SNs **do**
        if $SNs \in network$ **then**
            SNs get $MessREQ$ packet and store it
        else
            SNs out of coverage area (in sleeping mode)
        end if
        SNs send a copy of $PIRESP$ packet to BS
    end for
    for all $SNs \in network$ **do**
        BS broadcasts information table
    end for
end procedure
procedure GeoRoutingSPLL
    for all $SNs \in neighbours$ **do**
        if $distance_{(i)} \leq threshold$ **then**
            Send to target node
            if (SN) has two minimum distances equal and linked with two different nodes **then**
                if neighbor of $SN_1 < SN_2$ **then**
                    Select SN_1 as the next hop
                end if
            end if
        end if
    end for
    Send packet to the target node
end procedure

Fig. 2: Pseudocode for SPLL algorithm.

Many different paths to the destination means high tolerance against link failures but at the same time it will consume more node resources and bandwidth. So, direct communication, whenever possible, is certainly the best way for data dissemination. Geographic route SPLL takes the shortest path to reach the target while if a single node has two paths equal with the same distances to link the next hop to two SNs, the packet follows the node that has less number of neighbouring nodes connected to it. A node with many links leads to use this node for many paths to deliver other packets. Due to memory size for each node is limited for a few packets, device starts dropping packets when the queue size is full . Also, many links to individual node mean the processing data slows dramatically as the packets have to wait longer to deliver. Furthermore, it drains energy of device quickly because of advertising packets between nodes.

Figure 3 exhibits that all nodes are connected to each other using mesh topology. Each sensor is connected directly to the other neighbour devices based on the wireless sensing range. Therefore, node A wants to send its data to the BS through the intermediate nodes. The packet follows the shortest path to reach the ultimate receiver as shown in black rows. While node C is located on the route, it has two shortest paths to deliver node A packets into the next hop. In this case, node C takes the decision based on the SPLL policy which follows the node that has less number of neighbouring nodes connected to it as indicated by red arrows. Node B is depicted in dormant mode because of it being out of the radio coverage. The benefit of SPLL route is to send data within shortest path to minimize the energy consumption. Also, it avoids forwarding data to the nodes that have many neighbouring nodes, thereby balancing the load traffic and improving the network performance and lifetime.

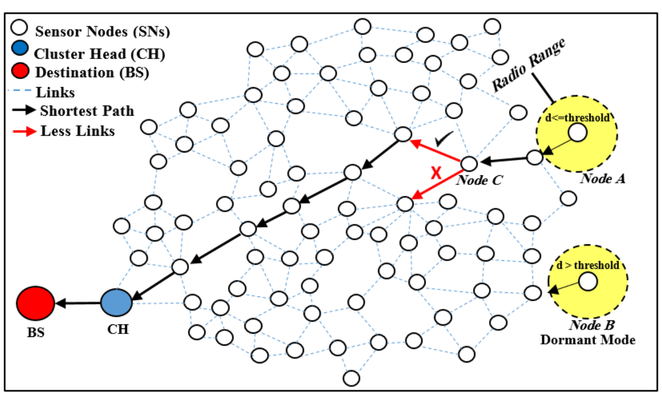

Fig. 3: Routing Structure of SPLL.

B. Long Hop Message Scheduling Algorithm

In multi-hop communication, with limited transmission range, a node depends on other intermediate nodes to be able to communicate with other nodes out of transmission range. These intermediate nodes act as relays for packets. This finding provides evidence that packets coming from nodes located on border use high number of hops to reach ultimate receiver. Also, it consumes a large amount of energy, memory and bandwidth during transmitting and receiving packets by other nodes.

The Fig. 4 explains the energy consumption for individual data packet at different nodes as a function of number of hops and distance. The plot was generated by randomly picking sixteenth nodes from a large network. Fig. 4 clearly indicates that data packet with higher hops "i.e. 14" uses maximum energy. When multiple data packet have same number of hops "e.g. 10", the one with higher distance consumes more energy. Due to this reason, it is beneficial to assign high priority for these data packets via a scheduling algorithm to conserve energy at the nodes. This is the key idea behind the LH algorithm where it provides priority to the packets based on sensors locations and number of sensors accessed.

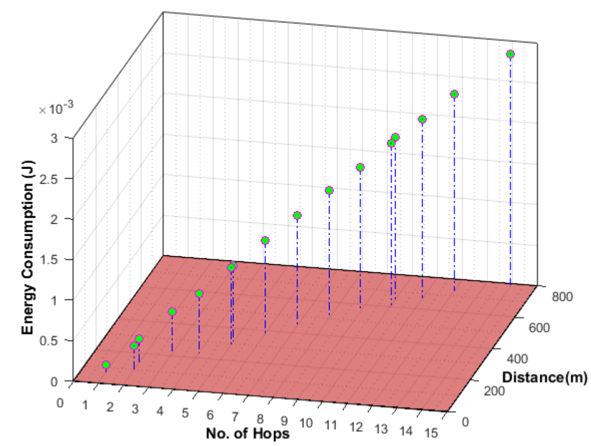

Fig. 4: Energy consumption by number of hops vs. distances.

The proposed algorithm is depicted in Fig. 5 which describes the method to schedule messages within long hops and far distances to serve first at the CHs. Firstly, LH analyses the messages coming from different sensors based on SPLL routing table. M/M/1 queuing model has been used to check the traffic intensity (P). Secondly, all messages must reach the base station through the cluster head nodes taking SPLL route policies. Finally, re-arranging of the messages based on the long hops and distances.

We assume that all sensors have the same capabilities (i.e. sensing, power, transmitting and receiving) ability. Task (T) comes with number of hops (N_{hops}) and distance (d) denoted as $T_d^{N_{hops}}$ to the intended destination. Let i be the number of sensors where $i = \{1, 2, 3, 4, ..., n\}$. If the task with $T^{N_{hops}} > T^{N_{hops}}(i)$ that means the task with $T^{N_{hops}}$ is served first at the cluster head to forward it to the next hop. While if there are more than two nodes have equal number of accessing sensors i.e., $N_{hops} = N_{hops}(i)$ and belong to the same queue at a CH node, the proposed algorithm takes into consideration of the sensors locations, i.e. if a node distance $T_d > T_d(i)$. Therefore, task with $T_d^{N_{hops}}$ is served first at cluster head to forward it to the BS. The pseudo code of the LH operation is shown in Fig. 5.

In order to see how the LH algorithm works, we analysed the data coming randomly from various SNs. Six real-time tasks as a part of the work are examined to explain the purpose of the proposed algorithm and can be seen in Fig. 6. These tasks belong within a queue at the CH nodes before delivering to the destination. Each task has different number

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of hops and distances. There must be at least a single task execution through CH to be forwarded to the exchange centre within one spin. LH algorithm re-sorts the tasks at CHs based on the biggest number of hops and longer distance to forward it first to ultimate receiver. If there are two packets equal with number of hops (as packets with yellow and purple colour in Fig. 6), the algorithm takes the second parameter (longer distance) into consideration. Based on the evaluation of the system traffic at the cluster heads, it can be seen that if traffic intensity is less than 1, single processor is active, and multi-core processor will be in sleep mode. However, if P is larger than 1, multi-core processor is activated to reduce the burden on cluster heads which serves multi-tasks within one cycle as depicted in Fig. 8.

Algorithm 2 : Pseudocode for LH message scheduling algorithm at CHs level

```
procedure PROCESSINGADVERTISEPACKETS
    For all nodes send data to ultimate receiver
    λ = 1/R_time
    μ = 1/T_trans
    Each Message has (R_time, T_trans)
    N_hops :number of hops from each node to the BS
    d :the distance from each source to the BS
    for Messages Traffic Intensity P do
        for all CHs ∈ network do
            P = T_trans/R_time
            if P < 1 then
                All nodes send messages to destination
            else
                sort messages Long Hops and far distances
                 in descending order
                if N_hops(i) = N_hops(j) then
                    if d_SN2 > d_SN1 then
                        Select the message has N_hops and
                         SN_2 as the first packet to deliver
                         it to the BS.
                        Active multi-core processor
                        Request messages in a T_trans/(m*
                        R_time)
                        Forward messages to the last
                         destination
                    end if
                else
                    Deliver message with greater N_hops
                     first to the BS
                end if
            end if
        end for
    end for
end procedure
```

Fig. 5: Pseudocode for LH scheduling algorithm.

C. System Model

1) Nodes Placement: Let N be the number of sensor nodes in the system model, and $loc = (x, y)$ is the location of each node. The distance d between two nodes is given euclidean mathematical method [34] as:

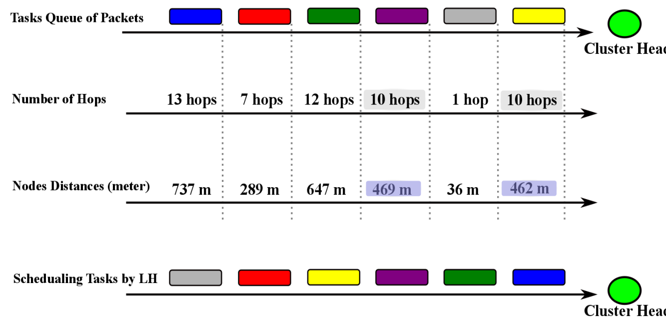

Fig. 6: The partial schedule of six tasks under LH algorithm.

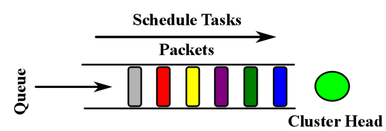

Fig. 7: LH technique with single-core processor.

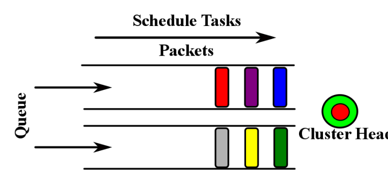

Fig. 8: LH technique with multi-core processor.

$$d_i = \sqrt{((x_i - x) + (y_i - y))^2}, i = 1, 2, 3, ..., N \quad (1)$$

SPLL routing technique is used to get shortest path (d_i) between these nodes to reach the ultimate receiver, i.e.

$$\sum_{i=1}^{N} d_i \rightarrow min \quad (2)$$

2) Energy Consumption Model: The aim of this study is to minimize the energy consumption and elongate the lifetime of the IoT networks. Most of the energy is consumed in listening, transmitting and receiving packets. Figure 9 illustrates the wireless communication model for energy dissipation used for the study [19, 35]. Each device has data in (DI) and data out (DO) interfaces. Packets enter the Radio Frequency (RF) module through the DI and buffer on it if the module cannot immediately process it. If the DI buffer becomes full, software or hardware flow control must prevent overflow and data loss, otherwise, the host must re-send it again [35]. Sensors network follow the SPLL route and LH scheduling strategy to deliver the packets to the next hop. The total energy consumed in the model is given as:

$$E_{Tx}(k,d) = k(E_{elec} + \epsilon_{amp} * d^2) \tag{3}$$

$$E_{Rx}(k) = k(E_{da} + E_{elec}) \tag{4}$$

where k is the number of bits per packet, and d denotes as the euclidean distance between two nodes. $E_{Tx}(k,d)$ is the total energy dissipated in the transmitting sensor node and $E_{Rx}(k)$ is the total energy depleted in the receiving sensor node. E_{da} is the energy dissipation for aggregation data. E_{elec} is presented the energy depleted to run the receiver or transmitter circuitry. ϵ_{amp} reveals the energy consumption for the power amplifier per bit, which can be calculated by eq. 5. Where ϵ_{fs} is the amplification coefficient of free space signal (d^2 as power loss) and ϵ_{mp} is the multi-path fading signal amplification coefficient (d^4 as power loss) are used. Their value depends on the distance between sender and receiver. d_0 is a threshold value calculated by eq. 6 [36]:

$$\epsilon_{amp} = \begin{cases} \epsilon_{fs} * d^2 & d \leq d_0 \\ \epsilon_{mp} * d^4 & d > d_0 \end{cases} \tag{5}$$

$$d_0 = \sqrt{\frac{\epsilon f_s}{\epsilon_{mp}}} \tag{6}$$

Nodes are classified into two groups: i) Non-CH nodes gather (k-bits of data) from the environment and directly disseminate it to a hop node or CH node. Where E_{GPS} and d_i are the power dissipation for global position system and distance between non-CH nodes to its CH respectively.Therefore, the energy exhaustion of a sensor node (E_{non-CH}) can be calculated by:

$$E_{non-CH} = E_{Tx}(k, d_i) + E_{GPS} \tag{7}$$

ii) CH nodes collect and compress the data coming from non-CH nodes, and then disseminate it to the ultimate receiver. Hence, the total energy consumed by cluster heads can be calculated by eq. 8 when M is the number of sensors sending packets to its CH and the d_i is the distance between CHs to the BS:

$$E_{CH} = ME_{Rx}(k) + E_{Tx}(k, d_i) + E_{GPS}, \tag{8}$$

A hop node depletes energy to send packet to another hop node. A hop node transmits and receives the information from L sensor nodes (i.e. hop nodes, or non-CH). The energy consumption by a hop node E_{hop} can be calculated by:

$$E_{hop} = LE_{Rx}(k) + E_{Tx}(k, d_{hop,CH}) + E_{GPS}, \tag{9}$$

Based on equations above, most of energy consumed in sensor nodes happens when transmitting data over large distances. Therefore, energy consumption can be reduced significantly by applying our proposed algorithms for the WSN enabled IoT networks.

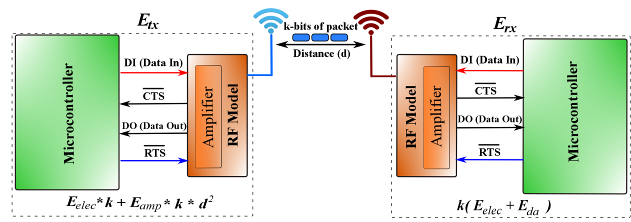

Fig. 9: The wireless communication model for energy dissipation.

3) Queuing Model: $M/M/1$ queuing model has been used in this study to calculate service rate and arrival rate for all messages coming from the nodes. $M/M/1$ is queuing theory within the mathematical theory of probability that shows the queue length of a single server in the system. Service times have an exponential distribution and arrivals are determined by a Poisson process [27]. Packets follow SPLL routing algorithm to reach the ultimate receiver through the CHs. Hence, LH scheduling algorithm is implemented at the CHs level. The service rate and arrival rate for m messages are introduced by μ and λ respectively. Traffic intensity (P) introduced for these messages is shown in eq. 12, eq. 13.

$$\lambda = \frac{1}{R_{time}} \tag{10}$$

$$\mu = \frac{1}{T_{trans}} \tag{11}$$

$$P = \frac{\lambda}{\mu} \tag{12}$$

$$P = \frac{T_{trans}}{R_{time}} \tag{13}$$

Then, the total traffic intensity (P_i) for the overall system in each IoT sub-group becomes as follows:

$$P_i = \sum_{1}^{n} \frac{\lambda}{\mu} = \sum_{1}^{n} \frac{T_{trans}}{R_{time}} < 1 \tag{14}$$

4) Network Buffer Sizing: Sensor devices have a very limited buffer or do not have it at all. Buffer (or data buffer) is a block of physical memory that temporarily stores packets until it is being moved. All network devices (i.e. sensors, gateway, routers, etc.) normally contain buffers to hold packets during congestion. As the network load increases, some packets drop due to excessive incoming traffic. Two well-recognized approaches for dimensioning network queues are the Stanford rule and the rule-of-thumb [37] [38]. Rule-of-thumb states that each link requires a buffer of size $B = RTT \times C$, where C is the bottleneck capacity and RTT is the average round trip time of the flow passing across the link. This rule is often applied at the edge or cluster devices of the network when the bandwidth capacity and number of flows are small. While the Stanford rule is used for large number of TCP flows and higher speed links. The recommended router requires a buffer of size $(RTT \times C)/\sqrt{n}$, where n is the number of TCP flows sharing the bottleneck link [37]. The rule-of-thumb has been used for this study since the flows at each CH is relatively small.

D. Complexity Analysis

The complexity of the proposed algorithms can be analyse in terms of storage and computational complexity. Most of IoT devices have small CPU that carries out the instructions of a computer program to send and receive packets. It is important to reduce the burden on this processor unit to prevent the fault. Therefore, the computational complexity is the major components in the analysis of the proposed algorithms. The time complexity of the SPLL routing protocol is $(3n^2 + n)$, where n is the number of nodes sender to the ultimate receiver. While the time complexity of the LH algorithm is (n^2+8n). The combination of both complexity is $(4n^2+9n)$. An algorithm is to be efficient when this function values is small. Therefore, the time complexity is obtained to be $O(n^2)$, which is similar or better than other protocols which have complexity in order of $O(n^2)$ and $O(n^3)$.

IV. Performance Analysis

In this section, we evaluate the performance of our proposed scheme by using simulation. The simulation is performed in the Matlab environment. We discuss the simulation parameters, environment and depict the simulation results. furthermore, these results are compared with other energy efficient schemes. In [22], the authors have shown their method to be superior to many other routing algorithms. Therefore, we have taken TBMS as the benchmark for the comparison. EDF is chosen for comparing the performance of the scheduling algorithm. IoT and smart city networks increase further the amount of SNs and sensing data generated. Therefore, we assume that a number of SNs are distributed randomly in the sensing area. All non-CH nodes gather the information from the sensing field and send the data to CHs or other hops. At each hop node, decision is made, based on the SPLL strategy and LH algorithm, on where to send the packet next. The CH nodes gather the data, compress and send it to the BS. All SNs have same initial energy and are non-chargeable, i.e. it can work until node death occurs. Previous studies focused on smaller network areas with less number of nodes. This setup is not consistent with the future IoT networks. Therefore, to prove that our proposed scheme is scalable, promising, well-designed and provides optimized energy usage, we analyse the system in detail by gradually increasing the area and number of nodes. The algorithm proposed provides an architecture for energy aware IoT system therefore is applicable to any real life applications such as [39, 40]. All parameters used in our simulation are listed in table I.

The total energy is determined as the summation of residual energy at all nodes in the network. Figure 10 shows the total energy when the sensing area is 200 m × 200 m with 100 nodes. Clearly, TBMS has slightly higher energy than other methods because of reduced multi-hop communication, thereby obtaining improved lifetime of nodes. In order to prove that our algorithms are promising for larger areas with many devices, the number of nodes and sensing area have been extended as shown in Table II. In Fig.11 to Fig.13, we observe that the proposed method achieves more energy savings than EDF and TBMS based algorithms. When EDF is used together with SPLL, the performance is better than TBMS. This is because SPLL uses sophisticated load balancing to shift traffic from one node to another to minimize node energy drain out and avoid network congestion. It also sends the packets from transmitter to receiver following the shortest path thereby shortening the effective distance. Furthermore, it balances the traffic load between nodes that leads to extended node lifetime. In large sensing area, TBMS takes time to collect all the information from the sensor nodes and scan the sensory field. Also, the random movement of mobile sink leads to increase the number of hops, and thus increased the average transmission distances that depletes the node energy. EDF technique does not assign high priority for packets coming from the longer distance. Therefore, quite a chunk of data is required to be retransmitted due to buffer size being full or TTL exceeded or quench source. Therefore, EDF with SPLL performs slightly worse than when LH is working together with SPLL. Moreover, multi-core processor can also be activated to reduce the retransmission of packets at CHs. The use of single and multi-core processors depending on

TABLE I: Parameters used in the simulation

Parameter	Value
Electronics Energy (E_{elec})	50 nJ/bit
Initial energy of node (E_{init})	0.25 J
Energy for GPS receiver (E_{GPS})	20 nJ/bit/signal
Energy for data aggregation (E_{da})	5 nJ/bit/signal
Communication energy (ϵ_{mp})	0.0013 pJ/bit/m^4
Communication energy (ϵ_{fs})	10 pJ/bit/m^2
Threshold value of distance (d_0)	87 m
Buffer size	202 bytes
Payload size	210 bytes
Header size	40 bytes
Retransmission overhead size	8 bytes + header size
Number of nodes (N)	100, 300, 500
Sensing Area ($M \times M$) m^2	200 × 200 , 500 × 500, 1000 × 1000
Algorithms	Multicore SPLL-LH, SPLL-LH, SPLL-EDF, TBMS

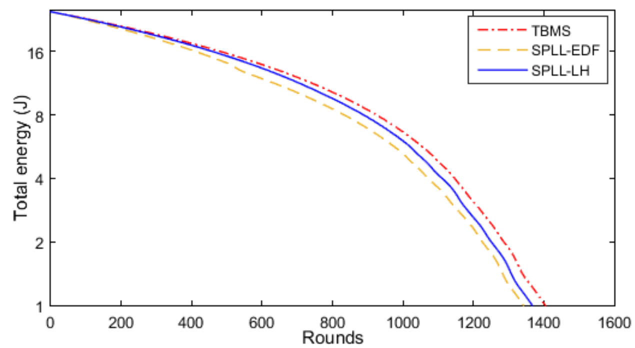

Fig. 10: Total network energy (100 nodes and sensing field=(200 × 200)m^2).

TABLE II: Number of nodes and sensing area used in the simulation

No. of Nodes	Sensing Area
100	200 m x 200 m
100	500 m x 500 m
300	500 m x 500 m
500	1000 m x 1000 m

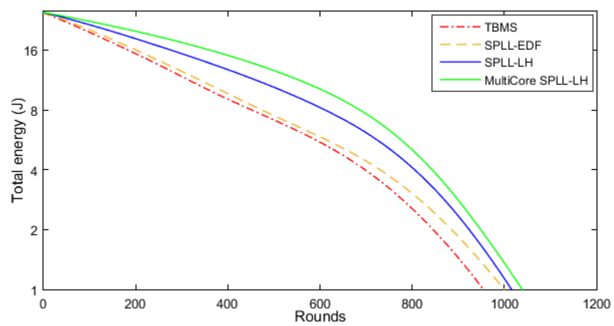

Fig. 11: Total network energy (100 nodes and sensing field=(500 × 500)m^2).

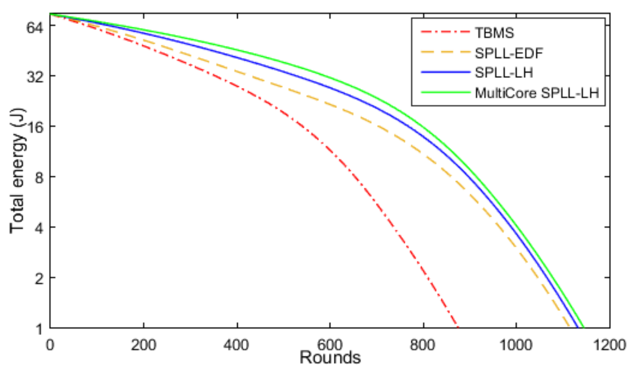

Fig. 12: Total network energy (300 nodes and sensing field=(500 × 500)m^2).

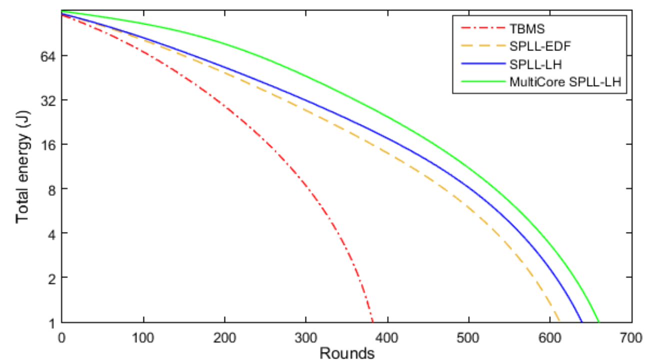

Fig. 13: Total network energy (500 nodes and sensing field=(1000 × 1000)m^2).

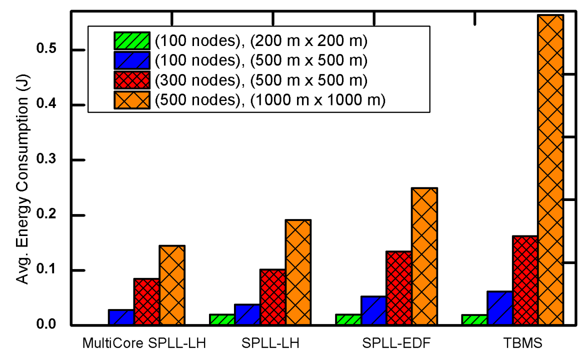

Fig. 14: Average energy consumption.

the network load improves the lifetime of network further. As mentioned in previous sections, IoT and smart cities are going to bring a large number of devices to be connect in a single network. These devices will be collecting data and sending it to the cloud utilizing WSN. The proposed algorithm will help balance the load traffic and reduce the use of many intermediate nodes to deliver the data to the BS for a large networks.

Figure 14 shows the average energy consumption for each round when the sensing area is 200 m × 200 m with 100 nodes, 500 m × 500 m with 100 nodes, 500 m × 500 m with 300 nodes and 1000 m × 1000 m with 500 nodes. The increase in average energy consumption for all the schemes is prominent when the sensing area and the number of nodes increase. However, the average energy consumption is much less than TBMS or EDF especially for the large network size with high number of nodes. This is consistent with Figs.10-13.

Next, we analyze the node deaths and see at which round first node, half node and last node death occur for a larger network area with higher number of SNs. The node death analysis is very important because once a node dies in a multi-hop network, the route needs to be updated, thus rapidly overloading other nodes leading to energy depletion on more nodes. Figures 15-17 show the rounds at which first node death (FND), half node death (HND) and last node death (LND) occur for all the schemes when the sensing area is 1000 m × 1000 m with 500 nodes. From these figures, it is evident that rounds of FND, HND and LND are higher for the proposed scheme.

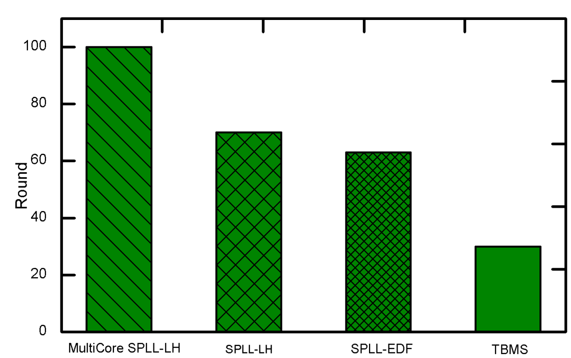

Fig. 15: First node death (500 nodes and sensing field=(1000 × 1000)m^2).

Transmission distance is the physical path between T_x and R_x within a single hop or multi-hop communication. It is reasonable to say that longer distances from source to intended destination will use higher transmission power. Therefore, reducing the transmission distance over the multi-hop path is a key factor in reducing energy consumption and time delay. Number of hops is the sum of all data relays occurred to reach the intended destination. Next hop depends on the type of routing algorithm used and network configuration. Less number of hops means lower latency and delays while a greater number of hops will degrade the performance of the data transfer, increase latency and delay and in some cases

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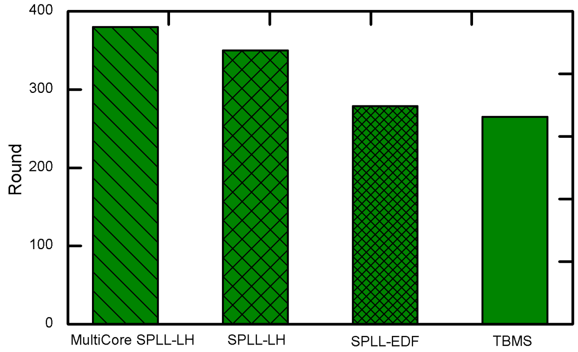

Fig. 16: Half node death (500 nodes and sensing field=$(1000 \times 1000)m^2$).

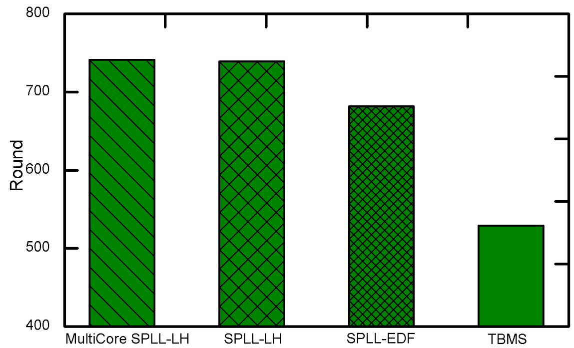

Fig. 17: Last node death (500 nodes and sensing field=$(1000 \times 1000)m^2$).

causes packet time out leading to retransmission. Figure 18 and 19 show the average transmission distances and average number of hops for all schemes when the sensing area is 200 m $\times$ 200 m with 100 nodes, 500 m $\times$ 500 m with 100 nodes, 500 m $\times$ 500 m with 300 nodes and 1000 m $\times$ 1000 m with 500 nodes. It is clear from the results that the proposed scheme has less average number of hops and transmission distances, especially for the larger areas and hence maintains a suitable latency for data transmission. This increases network sustainability and thus potentially extends the lifetime of typical smart city networks.

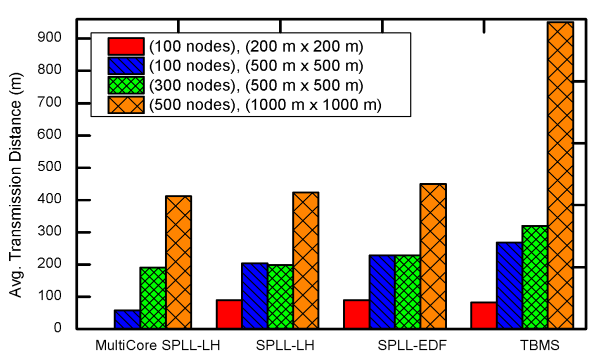

Fig. 18: Average transmission distance.

End-to-end delay [41] is the time taken by the bits to travel through the communication medium from the source to receiver. Delay time depends on congestion in the network and number of hops access to reach the intend destination.

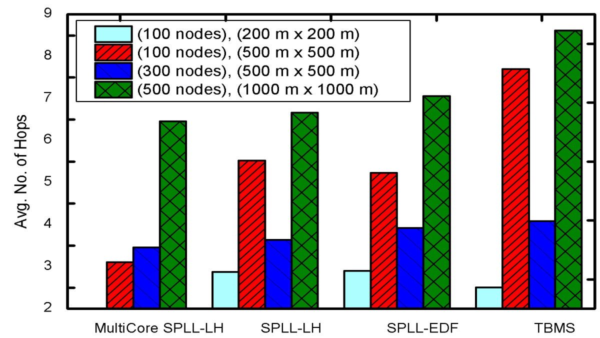

Fig. 19: Average number of hops.

Simulation setting has been adopted as in [42], where it takes 2 ms for a sensor node to make a transmission. The length of an interval period to update packets is 200 ms. Figure 20 shows the average delay time for different schemes. It shows that together with less average number of hops and transmission distance, the proposed scheme also has lower average delay time.

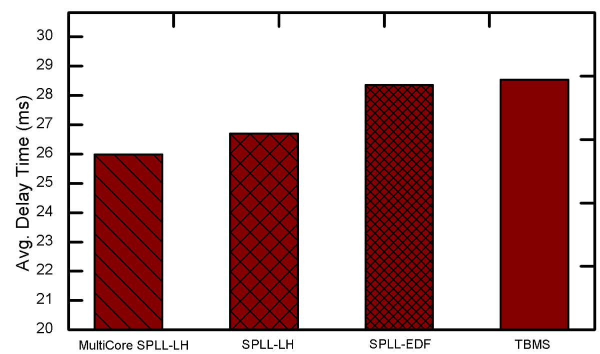

Fig. 20: Average time delay (500 nodes and sensing area = 1000 m $\times$ 1000 m).

Number of transmitted T_x and received R_x bytes are the sum of the packets sent and received from each node to the destination. Energy efficiency can be achieved by decreasing the number of transmitted and received bytes. Figure 21 shows the performance comparison of T_x and R_x data for four schemes and it is clear that the proposed method has overall lower average number of T_x / R_x packets in the network. We also investigate the throughput of the schemes. The percentage of successful data transmission from the sender to the BS for each round is called network throughput. As seen in Fig. 21, it can be seen that slightly better throughput is achieved. This is because of the efficient scheduling mechanism that prioritizes the packets traveling with longer hops or distance, thereby reducing the chances of packet drops.

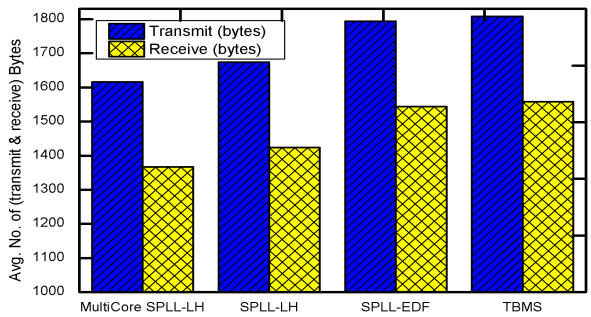

Fig. 21: Average transmitting and receiving bytes (500 nodes and sensing field=$(1000 \times 1000)m^2$).

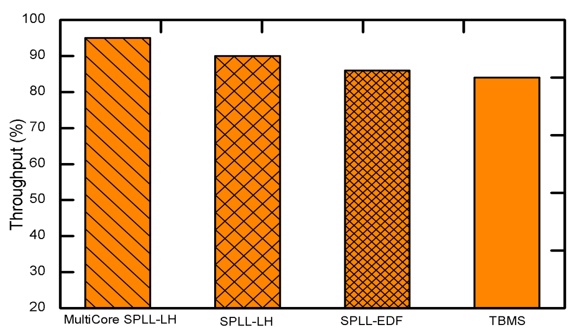

Fig. 22: Throughput (500 nodes and sensing field=$(1000 \times 1000)m^2$).

V. Conclusion

In this paper, an energy oriented path selection and message scheduling framework for sensor enabled wireless network environments has been presented. It was shown, form the design, development and analysis of the proposed framework, that the cooperation between path selection and message scheduling approach significantly improves energy efficiency in sensor enabled wireless network environments. The consideration of lesser number of links on path, closer message sender, longer hops, and processor availability reduces overall transmission energy requirement in message forwarding resulting in longer network lifetime. It is also observed that the proposed framework has lower energy consumption rate as compared to the state-of-the-art techniques. The communication round oriented network lifetime is longer considering energy exhausting in either first node, last node or half of the nodes in the network. In future, authors will focus on implementing heuristic based techniques for energy efficiency in sensor enabled wireless network environments.

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