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RESEARCH ARTICLE

Comparison of Data Rate and Energy Per Node of Wireless Sensor Network Under Small Scale Fading

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Abstract – In this paper two widely used algorithms: Maximum Flow and Open Shortest Path First (OSPF) are applied in a Wireless Sensor Network (WSN) to send information from a member node to a cluster Head (CH). Two parameters of wireless link: Shannon information rate and energy consumption per node for the above two algorithms are compared under three types of fading channels: Nakagami-*m*, Rician, and Rayleigh. To observe the impact of small-scale fading on the performance of the network, the steady state phase of WSN is considered instead of cluster formation. The final outcome of the paper is that the Nakagami-*m* channel is found as the best case and Rayleigh as the worst case, where Rician provides an intermediate result in the context of throughput. Again, the maximum flow algorithm provides better throughput compared to OSPF keeping the channel condition fixed. In the context of energy per node OSPF is found better than the case of maximum flow algorithm. The entire comparisons are shown both graphically and in tabular form. The combination of the maximum flow algorithm and Nakagami-*m* fading is found as the best to achieve maximum throughput whereas energy consumption per node totally depends on the topology of the network but the same combination shows the best result for most of the cases.

Index Terms – Maxflow Algorithm, OSPF, Energy Factor, SNR, Information Rate.

1. INTRODUCTION

The Wireless Sensor Network (WSN) is mainly used to collect physical, environmental, geographical, and biological data from remote locations. The data set over a long observation time are accumulated and processed at the central station then appropriate tools of machine intelligence are used to acquire the trend of data for future prediction. In WSN, sensing nodes transmit their information to the CH (cluster head) under both single and multiple hops. Since the height of the antenna of the sensing node is much lower than that of a conventional wireless network, therefore the wireless links will experience a huge number of obstacles, and links between any two nodes or nodes to CH can be modeled with a small-scale fading channel. A lot of applications of WSN are found in real-life and research works. For example, in [1], the profile of three environmental parameters: temperature, humidity, and carbon-di-oxide is determined by WSN. To increase the lifetime of the battery, a low-power architecture of the sensing node is proposed, where the microcontroller and sensors are kept disconnected during the inactive state of the sensing node. The same application of measurement of environmental information is found in [2]. The environmental parameters of the greenhouse are measured in [3] based on Arduino and Atmega328 microcontroller systems with temperature, light, humidity, and soil moisture sensors. In [4], authors proposed WSN to measure the real-time value of two important parameters of water: pH and temperature. Here ZigBee module is used for communication between nodes and CH to BS.

In [5] two types of dual-hop links: amplify-and-forward (AF) and decode-and-forward (DF) are applied to wireless sensor networks (WSNs) under the energy harvesting scheme. The impact of the time switching ratio and power splitting ratio on

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throughput is shown graphically for both AF and DF. Finally, the profile of normalized throughput in bits/sec/Hz against source transmission power, relay's efficiency, and distance of the source to destination are also shown explicitly. In [6] authors proposed a grid-based reliable multi-hop routing approach for WSN, where a data fusion center is used to eliminate redundant data. The authors provide two new algorithms: (i) adaptive grid formation algorithm (AGFA), which divides the network in a virtual grid-based monitoring section, and (ii) perception-based intra-cluster subdivision algorithm (PISA) to eliminate the node redundancy. The second case can reduce excess network traffic and the delay of the network is also minimized. Finally, energy consumption vs. round, round vs. the number of node failures, and latency vs. round are shown graphically with other models: DIRECT, LEACH, HEED, DEEC, and UCR. In [7], the limitation of the hop count of the multi-hop wireless network is considered, where authors find the applications of wireless sensor networks (WSNs), mobile ad hoc networks (MANETs), and wireless mesh networks (WMNs).

A framework is proposed for the stability of the wireless network then a relation is built up between the hop count and the stability of the network. In [8] the propagation model of the wireless link and attenuation of the signal in 'WSN radio frequency' are analyzed for telemedicine information transmission and reception under WSN. The paper deals with the free space signal propagation model, logarithmic distance path loss model as the large-scale fading, and normal distribution of signal as the small-scale fading.

The paper ignored the real-life fading models like Rayleigh, Nakagami-*m*, *Rician*, etc. The authors made an experiment using a PC and twelve ZigBee transceiver nodes to measure the received signal then it is compared with the free space model. In [9] a new concept of WSN is proposed where the sensor nodes are aided by unmanned aerial vehicles (UAV) and powered by power beacons (PBs). Here UAV of 5G is used to power up the cluster head (CH) and to collect aggregate data from it. The outage probability and throughput of WSN are derived with the assumption of Rayleigh and Rician fading environment between sensing nodes.

None of the above papers provides a distinct analysis of different fading models on the wireless links of sensing nodes even the average energy consumption of nodes of the network. The combination of the fading model with two algorithms: 'OSPF' and 'Maximum flow' is also a new concept used in this paper. The paper mainly focused on two parameters: 'data rate between source and destination node of WSN' and 'the ratio of data rate and the number of involved nodes' in the context of the communication energy model of WSN. Both the parameters are explained in section 3. The two parameters and two algorithms provide four variables, which are sent to a fusion center to select the appropriate algorithm. The main objective of the paper is to combine the fading model of the wireless channel, two data flow algorithms, and energy involved in data communication to acquire the most favorable decision under the complex environment wireless link.

The rest of the paper is organized as section 2 provides some related works. Section 3 deals with the basic concept of WSN, energy consumption model, OSPF, and maximum flow algorithm. Section 4 shows the methodology regarding steps of the entire operation. Section 5 provides results based on analysis of section 4. Finally, section 6 concludes the entire analysis.

2. RELATED WORKS

This section provides a few previous works of WSN related to energy consumption and data rate under fading channels. In [10], five different routing algorithms are considered in the determination of latency and energy consumption of WSNs. The profile of latency vs. number of nodes and energy consumption vs. simulation time is plotted for all the routing algorithms. The simulation shows the approximate linear relationship for both the cases but the profile of energy consumption for static and mobile sink cases is nonlinear. In [11], two MAC protocols of channel allocation: S-MAC and E-SMAC are applied in WSN to reduce unnecessary listening time of a sensor node. A simulation is run on the network to evaluate energy consumption under both protocols where E-SMAC outperforms S-MAC. The relative performance is shown graphically against simulation time. The throughput, packet delivery ratio, and latency are also found better for E-SMAC, whereas during the starting time, all the parameters are found closed for both the protocols but with the elapse of time the separation becomes wider. Properties of the cluster, CH, and clustering process are compared in the context of clustering algorithms in [12].

The energy consumption of three routing protocols: DWEHC, EDDUCA, and EEPC are compared graphically, where EEPC is found as the best. In [13], a fusion center is introduced in WSN, where sensor nodes send their signal in the fusion center under the Rican fading channel to make decisions under two hypothesis models. The probability of erroneous decision is shown under different combing schemes of wireless link varying parameters of fading channel.

A similar analysis is found in [14] under the Shadowed Fading Channel, where BER of WSN is evaluated against variation of SNR. The MAC protocol is combined with the fading channel in [15] to measure the SER and outage probability of WSN. None of the above papers relate to routing protocol and three prominent fading models to evaluate information rate and energy consumption per node of WSN. To collaborate with the sensing nodes of WSN a time synchronization routing technique is used in [16]. Although

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the time offset is found less than 100ms, but energy per node and fading channel of the wireless link are ignored. The summary of above related works is shown in Table 1.

Table 1 Summary of Related Works

Reference	Algorithm	Results	Limitation
[11]	Two protocols of the MAC layer: SMAC and E-SMAC are used for WSN.	Two graphical results: (i) Energy consumption vs. simulation time. (ii)Throughput vs. simulation time is considered.	No new algorithm to enhance the data flow of WSN and the fading of the wireless channel is ignored.
[12]	Three known algorithms: DWEHC, EDDUCA, and EEPC are used.	Energy consumption vs. number of nodes are shown against three protocols. Throughput is found beyond the scope of the paper	No explanation about the profile of energy consumption and properties of wireless channels.
[13]	CSI with the three-hypothesis model is used to evaluate the decision parameters.	Analysis of energy saving is done in short. The throughput of the network is ignored, only the probability of error at FC is considered.	Only the Rician fading channel is considered for WSN links in determining error at FC.
[14]	The bit error rate is determined for the shadow fading channel model.	Energy consumption is not considered. Instead of throughput, only BER is evaluated under multi-hop links.	The most widely used fading channel is ignored in the paper.
[15]	A new MAC protocol called HADF is applied under large and small-scale fading channels of WSN.	A parameter called: energy consumption per symbol is considered under average SNR. The SER and outage probability is shown graphically.	No complete solution of the energy model or throughput is found.
[16]	Time-synchronized routing is used in WSN.	Energy consumption is ignored but throughput is evaluated for three topologies.	Energy per node and fading of the WSN channel are avoided.
[17]	The proposed algorithm: ATREEN is used.	The number of rounds vs. 'lifetime of nodes' against four algorithms are compared.	The exact fading model is not found with routing and energy per node.
[18]	A new algorithm: QIEAC-SSBO is proposed.	The energy consumption, packet delivery ratio, packet drop rate, throughput, and delay are shown.	Only the basic multi-path propagation is considered.
[19]	Routing protocol: CDA aided by DCT is found.	The profile of the percentage of dead nodes, average network energy, and percentage of overhead energy are shown.	The throughput of the fading channel is not found.
[20]	The SOPR algorithm is applied to WBASN.	The message overhead, mean time to detect the black-hole attack, packet delivery ratio, network lifetime, and energy consumption are shown graphically.	The combination of routing, energy consumption, and fading channels is not found properly.
[21]	Cooperative and efficient routing protocol: CERP is used.	Compares the percentage of packet loss of CERP with the single hop model.	The SNR is not varied with the particular fading model.

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Explanations of a few recent works pertinent to this paper are mentioned below. In [17] authors proposed a new clustering protocol of WSN called 'adaptive threshold residual energy-based efficient sensor network protocol' (ATREEN) to choose a CH adaptively. The paper shows the energy model of the radio network, where a part of the energy is consumed by the electronics circuit, and the other part is absorbed by the power amplifier of the transmitting side. A combined model of the LEACH algorithm, energy utilization, and channel fading are shown with the mathematical explanation. The result section reveals several graphs relating the 'number of rounds' and 'lifetime of nodes' considering three techniques: LEACH, PEGASIS, and ATREEN. The exact fading model and throughput of the network were not found in the paper.

The relation among clustering of nodes, optimal route, energy consumption, and dynamic topology of WSN is addressed in [18] under the proposed algorithm called QIEAC-CSSBO. The energy-efficient clustering and optimal route path algorithm are shown explicitly. The energy consumption vs. the number of nodes, packet delivery ratio vs. the number of data packets, packet drop rate vs. the number of data packets, throughput vs. size of the data packet, and delay vs. the number of nodes are shown under QIEAC-CSSBO, Taylor C-SSA, and QEBSR. No particular fading model is followed, only multipath propagation is mentioned in the paper.

Due to the complex environments of WSN, the energy-efficient routing protocols are a big challenge for the researchers. The degree of nodes on the topology of the WSN affects the lifetime of the network. The paper [19], deals with a Collaborative Distributed Antenna (CDA) routing protocol considering the Degree Constrained Tree (DCT) to enhance the stability period of the network. In the result section, the percentage of dead nodes, average network energy, and percentage of overhead energy are shown graphically against the number of rounds under six different protocols, where two of them are proposed models and the rest four are conventional algorithms. The throughput and fading model of the wireless channel are ignored in the paper. In [20] authors claim a reliable, energy-efficient, and secured protocol called Secure Optimal Path-Routing (SOPR) for Wireless Body-Area Sensor Networks (WBASN). The algorithm of 'energy efficiency with reliability' and the routing protocol of SOPR are shown in detail. The result section of the paper deals with black-hole attacks, network lifetime, and energy consumption. The message overhead, mean time to detect attack, packet delivery ratio, network lifetime in ms, and energy consumption in Jules are presented graphically considering three previous methods: ATTEMPT, M-ATTEMPT, Rahat method, and the proposed method: pro-SOPR-BEER.

To address 'limited resources' and 'routing technique with energy efficiency' authors in [21] proposed a cooperative communication model of relayed wireless link called 'cooperative and efficient routing protocol (CERP)'. The result section compares the percentage of packet loss of CERP with Direct Transmission and RPL transmission. The performance of CERP increases with increment of relays keeping SNR and data rate fixed are also visualized from the same graph. None of the above papers provide the composite model to WSN including routing protocol, energy per node, and fading channel of wireless link. The phenomenon is considered as the research gap in favor of this paper.

3. BASIC OF WSN

Wireless sensor networks (WSNs) is a self-configured and infrastructure-less wireless networks (like MANET) that consist of a large number of **sensor nodes** to monitor the physical or environmental conditions of the sensor field. A sensor node consists of sensing (measuring), computing (calculating any change in value of sensor output in digital form), and communication elements. Sensor nodes in the vicinity of a certain predefined region form a cluster. Each cluster contains a cluster head (CH) responsible for collecting and routing data from its nodes to a base station. The basic components and data flow system of a WSN is shown in Figure 1.

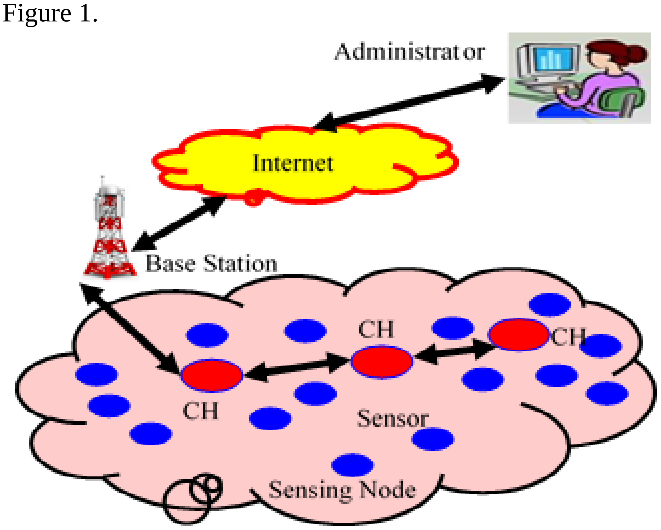

Figure 1 Basic Components of WSN

The main challenge of WSN is the formation of clusters with almost the same radius (also non-overlapping cluster nodes) and cluster heads that are the best positioned in the cluster. Once the cluster is formed then the network enters the steady-state phase of data communication. The acquired data (or information) by member nodes is passed to the corresponding CH, finally, CHs send the combined data to sink through the Internet, where administrators monitor and analyze them.

3.1. Energy Consumption Model of WSN

The energy consumption of each sensor node is divided into two parts: (i) sensing and signal processing part and (ii) data transmission part is expressed as [22].

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$$E = \theta + \eta\omega d^n \quad (1)$$

Where θ is a part of the total energy E used by the electronics components of a sensing node, which is independent of distance. The second part $\eta\omega d^n$ is related to data transmission, where η represents the amplifier inefficiency factor i.e. reciprocal to the efficiency of a power amplifier. The factor η considers the sum of used energy in power amplification and the lost energy of the amplifier. The parameter ω is the free-space path loss, d is the distance, and n is the path-loss exponent.

The eq. (1) is modified for energy in terms of Joule/bit reduces with the incorporation of information rate R like,

$$E = \frac{1}{R}(\theta + \eta\omega d^n) \quad (2)$$

Where R is the information rate in bits/sec

If the number of involved nodes is N in communication then eq. (2) becomes like eq. (3),

$$E = \frac{N}{R}(\theta + \eta\omega d^n) \quad (3)$$

The basic of energy consumption models of WSN are found in [22] and the same idea in dB form is found in [23].

The eq. (1) to (3) considers the free space path model on the wireless links of sensing nodes. In this paper, the wireless path (or channel) between the sensing node and CH is considered to experience small-scale fading like Nakagami-*m*, Rician, and Rayleigh. In the Rayleigh fading case there is no line of sight (LOS) from CH to sensing nodes, in Rician fading there is a strong LOS but the rest of the links are non-LOS and in Nakagami-*m* fading there are *m* weak links between CH and sensing nodes found in [24-27] in context of the short and long wireless link. The probability density function (pdf) of Rayleigh, Nakagami-*m*, and Rician taking SNR as the random variable is given below in eq. (4), (5), and (6) as found in [28].

$$f_{\Gamma}(\gamma) = \frac{1}{\gamma_{av}} e^{-\frac{\gamma}{\gamma_{av}}} \quad (4)$$

$$f_{\Gamma}(\gamma) = \frac{m^m \gamma^{m-1}}{\gamma_{av}^m \Gamma(m)} e^{-\frac{m\gamma}{\gamma_{av}}} \quad (5)$$

Where m is the fading parameter and $m \geq 1/2$

$$f_{\Gamma}(\gamma) = \frac{(1+n^2)e^{-n^2}}{\gamma_{av}} e^{-\frac{(1+n^2)\gamma}{\gamma_{av}}} \quad (6)$$

Where n is the fading parameter and $n \geq 0$

The above three models are applied to two data flow algorithms of the next sub-section. In this paper, nodes are considered stationary, and high-speed moving objects between two adjacent nodes are ignored, therefore variation of SNR is less prominent compared to mobile nodes of MANET.

3.2. OSPF and Maximum Flow Algorithm

Maximum possible throughput of WSN under the flow of multi-hop but single-path from source to destination is done using the Open Shortest Path First (OSPF) algorithm. Here the shortest path means the combination of links in series with maximum SNR or maximum capacity in bps found in [29-30]. The complete solution of multi-hop and multiple path wireless link (with channel capacity) is possible with a maximum flow algorithm (also called Max flow). The Max flow algorithm always starts with the zero flow. On each iteration, the algorithm finds a path from source to sink. If the path provides some additional flow then it is called the 'path of augmenting data flow' and the flow is updated. The algorithm terminates when no augmenting path is found and the current flow is considered as the optimal by *Ford-Fulkerson* method like [31].

4. METHODOLOGY

The conceptual view of WSN under the fading channel is shown in Figure 2. Here SNR_{ij} is the SNR between sensing nodes i and j, C_{ij} is the corresponding channel capacity and x_{ij} is the current information rate. The parameter $w(i, j) = S\text{-}C_{ij}$, where S is a large positive number, is used in the OSPF algorithm to make the weight of the graph equivalent to the distance between adjacent nodes.

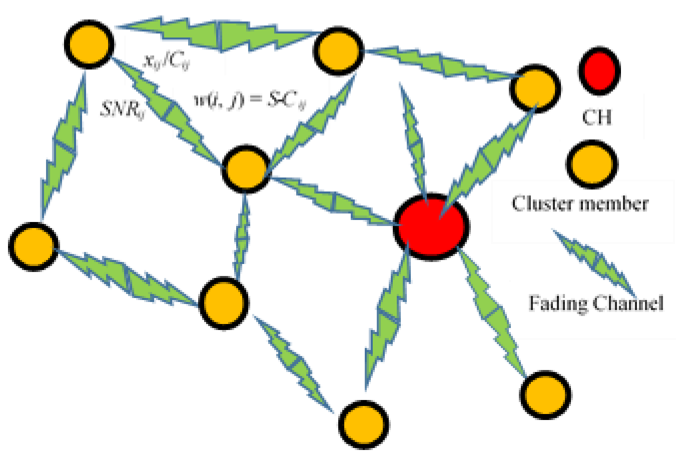

Figure 2 Conceptual View of WSN under Max Flow and OSPF Algorithm

In the Max flow algorithm, if a sensing node j is connected with a sensing node i then the node j is labeled as: (l_j, i+), where l_j=min(C_{ij}-x_{ij}, l_i) and i+ indicates the increment of information rate of the edge e_{ij}. According to the Max flow algorithm the reveres flow of data or decrement of present flow, the node j will be labeled as (l_j, i-) shown in details in [32]. The application of the algorithm is found in [23-35],

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under communication networks. The entire algorithm of Max flow in the context of WSN is given below numbered as Algorithm 1.

//Input: WSN with a source node s and a sink node n

//Output: A maximum flow x

for all edge e_{ij} determine, SNR_{ij} and $C_{ij} = \log_2(1+ SNR_{ij})$

Initially assign current flow $x_{ij} = 0$ to every edge e_{ij}

mark each edge as x_{ij} / C_{ij}

Using BFS (Breadth First Search) algorithm determine augmenting path as:

for each e_{ij} do //for the direction of forward paths or edges

if j is still unlabeled then

$r_{ij} \leftarrow C_{ij} - x_{ij}$

if $r_{ij} > 0$

$l_j \leftarrow \min\{l_i, r_{ij}\}$; label the node j with l_j , mark the source i+

for each e_{ij} do //for the direction of backward paths or edges

if j is still unlabeled

if $x_{ji} > 0$

lj $\leftarrow \min\{li, x_{ji}\}$; label tye node j with l_j , and the source node i−

if the sink is already labeled

move backward till source assigning j = n

if label of the node j is positive then

$x_{ij} \leftarrow x_{ij} + l_n$

else

$x_{ji} \leftarrow x_{ji} - l_n$

Continue BFS algorithm until no augmenting path is found

Return the maximum flow x.

Algorithm 1 Maximum Data Flow of WSN

In the OSPF algorithm distance of the source node *s* of the WSN is considered as $d_s = 0$ as the initial value. The source node *s* has two adjacent vertices *p* and *q* and the weight of the edges e_{sp} is represented as $w(s,p)$ and that of e_{sq} is $w(s, q)$. The distance between *s* to *p* and *s* to *q* are represented as $d_p = d_s+w(s, p)$ and $d_q = d_s+w(s, q)$ respectively. Initialize the distance of all the nodes *v* from the source *s* with the value of infinity and insert them in a priority queue as Insert(Q, v, dv). Any update of the queue with node *p* and its distance d_p is indicated as Update(Q, p, dp). All the visited vertices are put in the set V_T (initially a null set ∅) and the unvisited vertices are under the set $V\text{-}V_T$. The element with minimum distance is deleted from the priority queue is represented as the function, Mindel(Q), and the deleted element is added with the set V_T. The algorithm will stop when $|V| - 1$ vertices are visited. The same algorithm was previously applied in WSN and LEO satellite communication found in [36-37]. The entire algorithm of OSPF under WSN is given below in detail under the caption of Algorithm 2.

//Input: The weighted graph of WSN, G=(V,E)

//s is considered as the source node and v is the sink or destination node of the network

for all edge e_{ij} determine, SNR_{ij} and $C_{ij} = \log_2(1+ SNR_{ij})$

initialize the weights edges of the graph as: w(i, j) = S-C_{ij}, where S is a large positive number

//Now w(i, j) resemble to the distance between node i and j of OSPF

//Output: The shortest path from source to destination

Initialize(Q) //the priority queue, Q is initializes as empty

for all the vertices v of the WSN

dv ← INF;

Insert(Q, v, dv)

ds ← 0; Update(Q, s, ds)

$V_T \leftarrow \emptyset$

for i ← 0 to |V | − 1 do

$u_r \leftarrow$ Mindel(Q)

$V_T \leftarrow V_T \cup \{u_r\}$

for every unvisited vertex: $u \in V - V_T$ and adjacent to u_r do

if $du_r + w(u_r, u) < du$

$du \leftarrow du_r + w(u_r, u)$;

Update (Q, u, du)

Algorithm 2 OSPF in WSN

In OSPF, the distance equivalent variable $w(i, j) = S\text{-}C_{ij}$ between node *i* and *j* is a function of $SNR_{i,j}$ and in the Max flow algorithm, the three variables: capacity C_{ij}, current flow x_{ij}, and remaining flow all are the function of $SNR_{i,j}$. Again, $SNR_{i,j}$ depends on the fading model of the wireless link, and its instantaneous value is determined from eq. (3)-(5) after long-term observation of received SNR of each node. From statistical analysis of the received SNR of a sensing node, the decision is taken about the pdf of the fading channel. Next, both the above algorithms are applied to the sensor nodes of the sensing field to acquire the maximum possible data flow from the source node to any sink node. Another decision is taken about each cluster of the WSN to choose the appropriate

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algorithm. A basic workflow diagram of the decision against each cluster of the network is shown in Figure 3 and all the decisions are sent to the fusion center to preserve it for some observation time (possibly for the duration, the statistical distribution of the fading channel remains identical). Both the algorithms: Max flow and OSPF store the Hamiltonian path from source to destination node, which provides the number of involved nodes *N* of the path. Now, *N/R* of eq. (3) gives the indication of energy per bit.

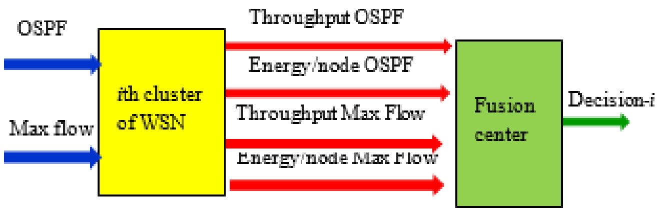

Figure 3 Basic Workflow of Decision of the Entire WSN

The steps of the entire work of the paper are given below under Algorithm 3, considering both data rate and energy per node.

a. Mark the sensing nodes of the WSN as A, B, C, etc.

b. Determine the SNR of each link SNR_{A-B}, SNR_{C-F}, SNR_{B-G}, etc.

c. Determine the channel capacity of each link C_{A-B}, C_{C-F}, C_{B-G}, etc.

d. Taking SNR_{I-J} or C_{I-J} draw the equivalent weighted graph of the network

e. Determine adjacency matrix G[v][v] of the weighted graph, where v is the number of vertices of the graph.

f. Apply OSPF Algorithm on the graph equivalent matrix G[v][v] to find the shortest path from a source node s to any destination k. Store the number of involved nodes N_1 of the series link.

g. Determine the maximum possible data flow R_1 of the series link of the shortest path.

h. repeat step f for the Max flow algorithm to find the maximum possible data flow R_2 from a source node s to a sink node k.

i. Store the number of involved nodes N_2 under all the augmenting paths.

j. Compare the data flow of steps g and h.

k. Compare the N_1/R_1 and N_2/R_2 as the energy per node of two algorithms.

l. Repeat steps b to k for Rayleigh, Rician, and Nakagami-m fading cases.

m. Apply the results on the fusion center of Figure 3 and take the decision.

Algorithm 3 Composite Operation

The utilization of Max Flow and OSPF algorithms will improve the information rate of the network but computational complexity and resource limitations of the network will be the main concern in implementation of the proposed model of the paper. The proposed methodology assumes that the wireless channels remain static for some observation time as mentioned above, but in the real world, the channel changes continuously. Therefore, such an assumption will make some difference between theoretical and practical data rates. The results based on the methodology of the papers are given in the next section.

5. RESULTS

First of all, a comparison is made for data rate and energy per node of OSPF and Max flow algorithm under the Rayleigh fading channel of WSN. The instantaneous *SNR* of each link of a cluster of the WSN (equivalent to a weighted graph) is evaluated considering an average *SNR* of 5dB shown in Figure 4. Here 19 nodes are taken as an example (each one is a sensor node) using the symbols *A*, *B*, *C*…*S*, where *A* is the cluster head (CH). Using Shannon's channel capacity with bandwidth, *B* = 300Hz, the capacity of each link is shown as the weight of the graph of Figure 4. For a particular topology of WSN, the degree of a node, SNR of its links, fading environment and routing algorithm govern its throughput and energy consumption. Therefore, the wide variation of the performance of nodes is visualized from all the graphs of the paper.

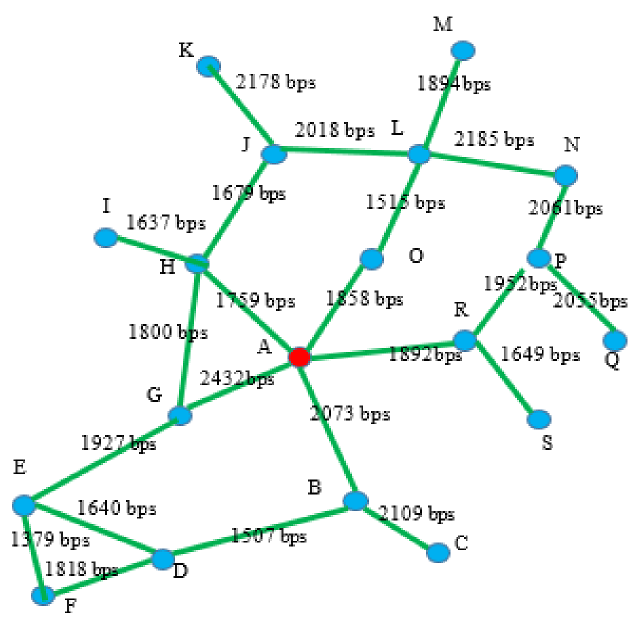

Figure 4 Equivalent Weighted Graph of a Cluster

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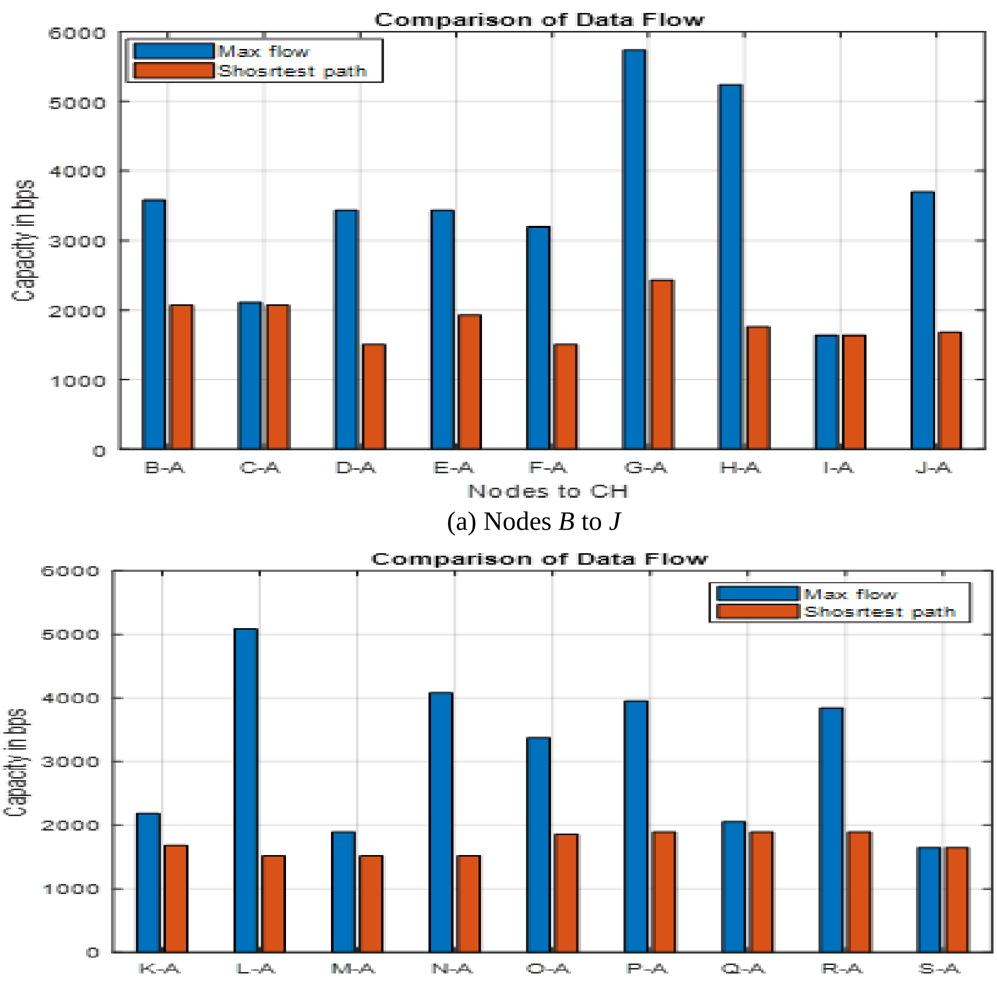
The OSPF algorithm is applied on each node (*B*, *C*, *D*,…, *S*), except node *A* (or CH), which is considered as the sink to evaluate the maximum possible data flow. In this research work the source node, and its repeater nodes on the OSPF and the CH are considered active and the rest of the nodes are taken inactive like the superposition theorem. Data flow from each node to sink, like *B* to *A* (or 2 to 1), *C* to *A* (or 3 to 1), and *D* to *A* (or 4 to 1) till *S* to *A* (or 19 to 1) are evaluated using Matlab 18. Similarly, data flow using the 'Max flow' algorithm (Ford–Fulkerson algorithm using augmenting path) is also used to determine flow from sources (all nodes except A) to sink (Node A). The data rate or capacity found from the above two algorithms is shown in the bar graph of Figure 5 (a) and (b), where Figure 5(a) shows the comparison of flow for node *B* to *J* and Figure 5(b) shows that of rest of the nodes *K* to *S*. It is obvious that capacity of Max flow algorithm is far better than that of OSPF. The mean flow of OSPF is found 1.7778Kbps and that of the Max flow is 3.3431Kbps. In OSPF fewer nodes are used from source to sink compared to the Max flow algorithm. Therefore, there is a tradeoff between energy consumption per node and the information rate between sources to sink. The entire scenario is visualized in Table 2, where the Max flow algorithm involves more nodes compared to OSPF at the same time data rate of the Max flow algorithm is also higher than that of OSPF. Figure 6 shows the involved nodes and corresponding edges for the first four rows of Table 2 under both algorithms. Comparison of the information rate of two algorithms for average *SNR* of 2dB, 8dB, and 12 dB are shown in Figure 7(a)-(b), Figure 8(a)-(b) and Figure 9(a)-(b) respectively. It is obvious that data flow increases with the increment of average SNR and the relative performance of 'Max flow' and OSPF remains as usual. A comparison of the mean data rate of the two algorithms is shown in Table 3, where the Max flow algorithm provides almost double the data rate compared to OSPF, although the relative performance depends on the topology of WSN.



(a) Nodes *B* to *J*

(b) Nodes *K* to *S*

Figure 5 Comparison of Max Flow and OSPF (Average SNR = 5dB)

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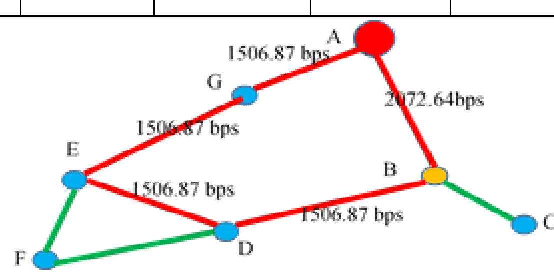
Table 2 Comparison of Ford–Fulkerson Algorithm and OSPF (Average SNR = 5 dB)

Source to destination	Max flow algorithm			OSPF		
	Path from nodes to CH	No. of involved nodes	Link capacity in kbps	Path from nodes to CH	No. of involved nodes	Link capacity in kbps
B-A	(B – A) + (B-D-E-G-A)	5	3.580	B-A	2	2.073
C-A	(C-B-A) + (C-B-D-E-G-A)	6	2.109	C-B-A	3	2.073
D-A	(D-B-A) + (D-F-E-G-A) + (D-E-G-A)	7	3.434	D-B-A	3	1.507
E-A	(E-G-A) + (E-D-B-A)	5	3.434	E-G-A	3	1.927
F-A	(F-D-B-A) + (F-E-G-A)	6	3.197	F-D-B-A	4	1.507
G-A	(G-A)+(G-E-D-B-A)+(G-H-A)+(G-H-J-L-O-A)	9	5.738	G-A	2	2.432
H-A	H-A+(H-G-A) + (H-J-L-O-A) + (H-J-L-N-P-R-A)	9	5.239	H-A	2	1.759
I-A	I-H-A	3	1.638	I-H-A	3	1.638
J-A	(J-H-A) + (J-L-O-A) + (J-L-N-P-R-A)	8	3.698	J-H-A	3	1.679
K-A	(K-J-H-A) + (K-J-L-O-A)	6	2.179	K-J-H-A	3	1.679
L-A	L-O-A + (L-J-H-A) + (L-N-P-R-A)	8	5.086	L-O-A	2	1.515
M-A	M-L-O-A + (M-L-J-H-A)	6	1.894	M-L-O-A	3	1.515
N-A	N-P-R-A + (N-L-O-A) + (N-L-J-H-A)	8	4.077	N-P-R-A	3	1.515
O-A	(O-A) + (O-L-J-H-A)	5	3.373	O-A	2	1.858
P-A	(P-R-A) + (P-N-L-O-A) + (P-N-L-J-H-A)	8	3.953	P-R-A	3	1.892
Q-A	Q-P-R-A+(Q-P-N-L-O-A)	7	2.055	Q-P-R-A	4	1.892
R-A	(R-A) + (R-P-N-L-O-A) + (R-P-N-L-J-H-A)	8	3.843	R-A	2	1.892
S-A	S-R-A	3	3.580	S-R-A	3	1.649

The results of Table 2 can be compared with conventional OSPF and Max flow algorithm. For example, ignoring small-scale fading of the wireless channel, the information rate from source node D to sink node A (third row of Table 2) under the OSPF of [38-39] is 1.993Kbps and that of Max flow of [40] is 5.979 Kbps using the same parameters. Both the results are higher than that of Table 2, since the incorporation of the fading channel the performance of the network deteriorates, which reflects the real scenario of WSN.



(a) B-A Max flow

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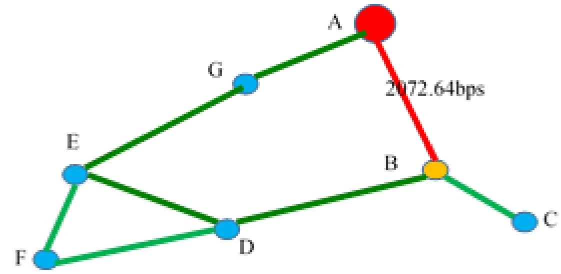
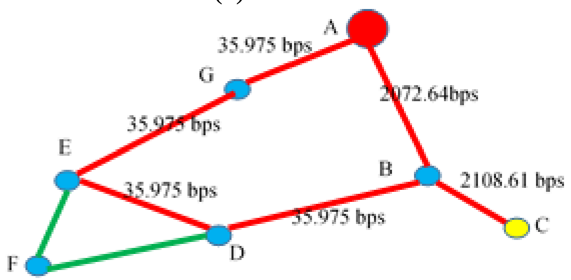
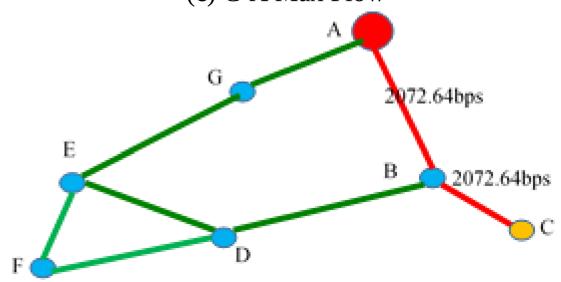


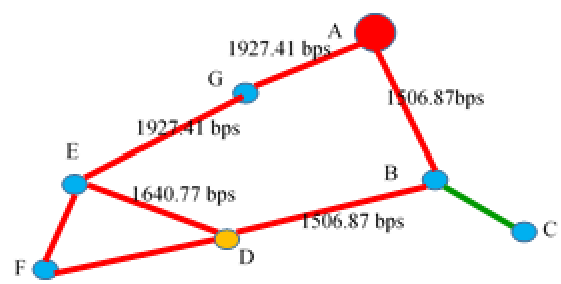
(b) B-A OSPF



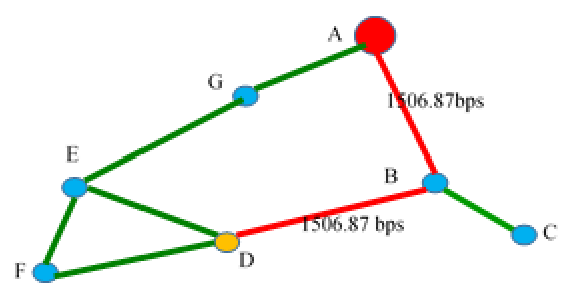
(c) C-A Max Flow



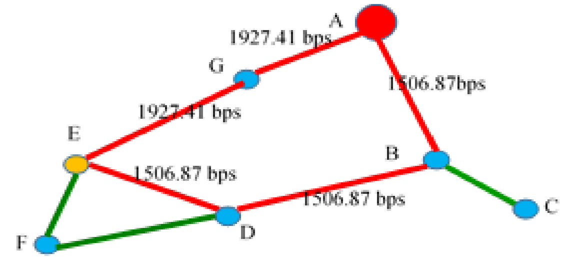
(d) C-A OSPF



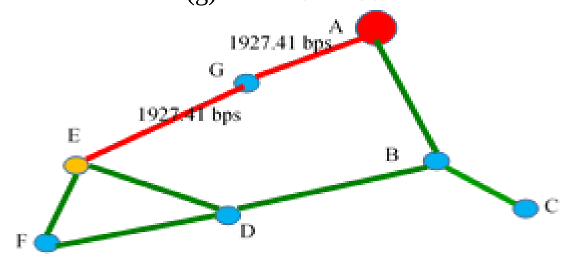
(e) D-A Max Flow



(f) D-A OSPF

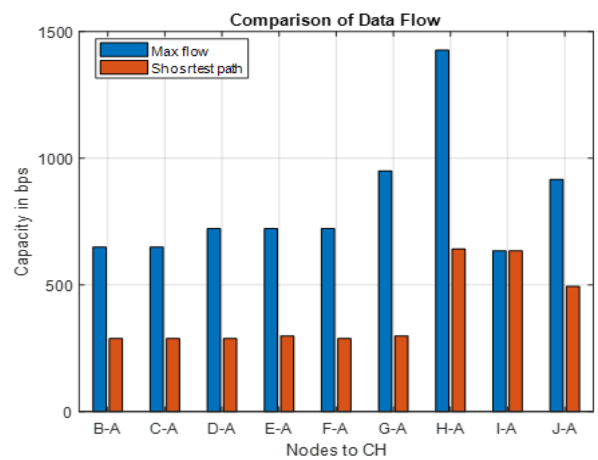


(g) D-A Max Flow

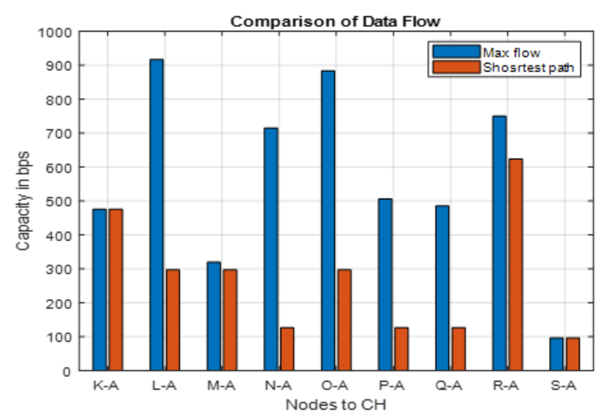


(h) D-A OSPF

Figure 6 Involvement of Nodes from Source to Sink Under Two Algorithms

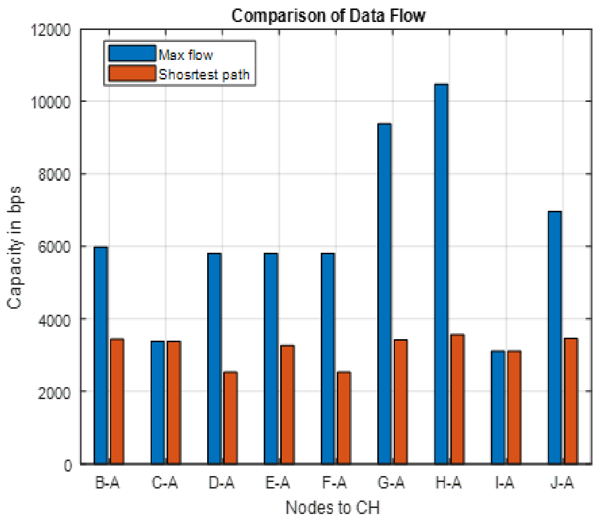


(a) Nodes *B* to *J*

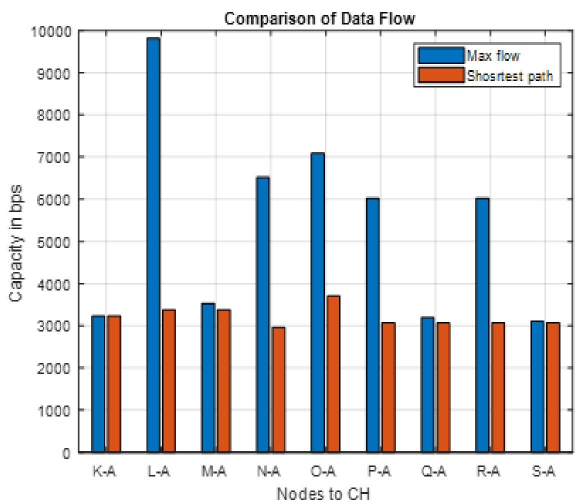


(b) Nodes *K* to *S*

Figure 7 Comparison of Max Flow and OSPF (Average *SN*R =2dB)

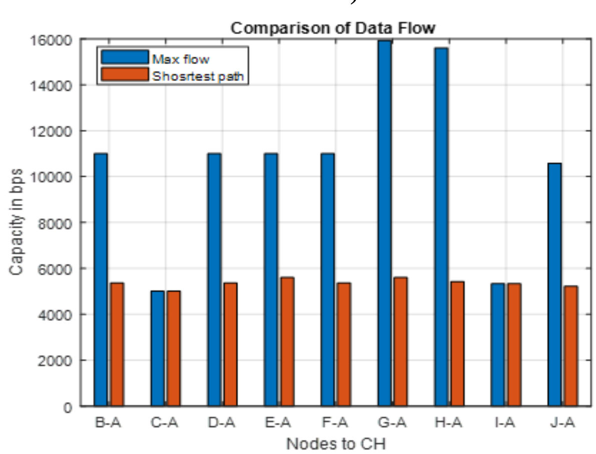


(a) Nodes *B* to *J*

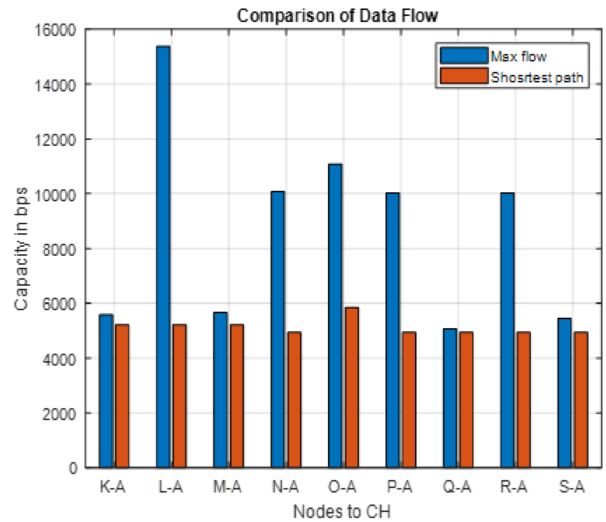


(b) Nodes *K* to *S*

Figure 8 Comparison of Max Flow and OSPF (Average SNR =8dB)



(a) Nodes *B* to *J*



(b) Nodes *K* to *S*

Figure 9 Comparison of Max Flow and OSPF (Average SNR =12 dB)

Table 3 Comparison of Mean Data Flow

Average SNR in dB	OSPF in bps	Max Flow bps
2	339.5759	627.5835
5	1.7778e+03	3.3431e+03
8	3.1125e+03	6.0018e+03
12	5.1108e+03	9.4873e+03
16	1.3269e+04	7.1904e+03
20	1.6838e+04	9.0430e+03
25	2.1564e+04	1.1728e+04

Applying the first row data of Table 2 (for *B-A* communication) in eq. (3), the exact energy consumption becomes like eq. (7) for Max flow algorithm,

$$E = \frac{5}{3.5795e+03}(\theta + \eta\omega d^n) = 1.39 \times 10^{-4}(\theta + \eta\omega d^n) \quad (7)$$

Similarly, eq. (8) is found for OSPF,

$$E = \frac{2}{2.0726e+03}(\theta + \eta\omega d^n) = 9.65 \times 10^{-4}(\theta + \eta\omega d^n) \quad (8)$$

The smaller the factor *N/R*, the less energy is consumed per node. Here OSPF consumes less energy at the expense of data rate. From Table 2 the factor *N/R* for 'Max flow' and OSPF is shown in Table 4. From the table, it is visualized that for most of the cases, the factor *N/R* is found smaller for the OSPF case, and the corresponding bar graph is shown in Figure 10 (a)-(b) to observe the phenomenon at a glance.

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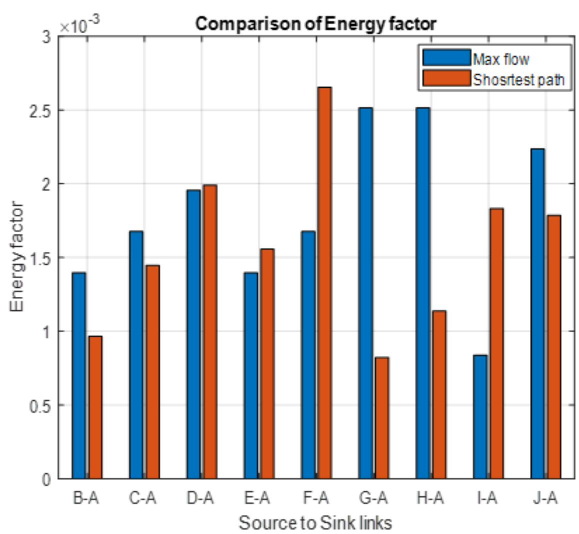
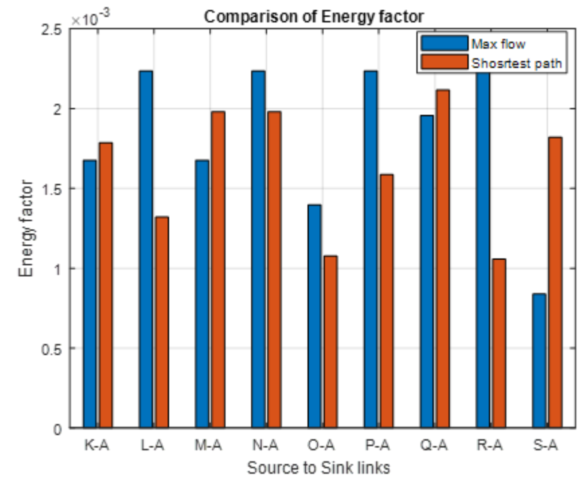
Table 4 Comparison of N/R

Source to CH	Max flow (N/R)	OSPF (N/R)
B-A	0.00139684	0.000965
C-A	0.00167621	0.001447
D-A	0.00195558	0.001991
E-A	0.00139684	0.001557
F-A	0.00167621	0.002654
G-A	0.00251432	0.000823
H-A	0.00251432	0.001137
I-A	0.00083811	0.001832
J-A	0.00223495	0.001786
K-A	0.00167621	0.001786
L-A	0.00223495	0.00132
M-A	0.00167621	0.00198
N-A	0.00223495	0.00198
O-A	0.00139684	0.001076
P-A	0.00223495	0.001586
Q-A	0.00195558	0.002115
R-A	0.00223495	0.001057
S-A	0.00083811	0.00182

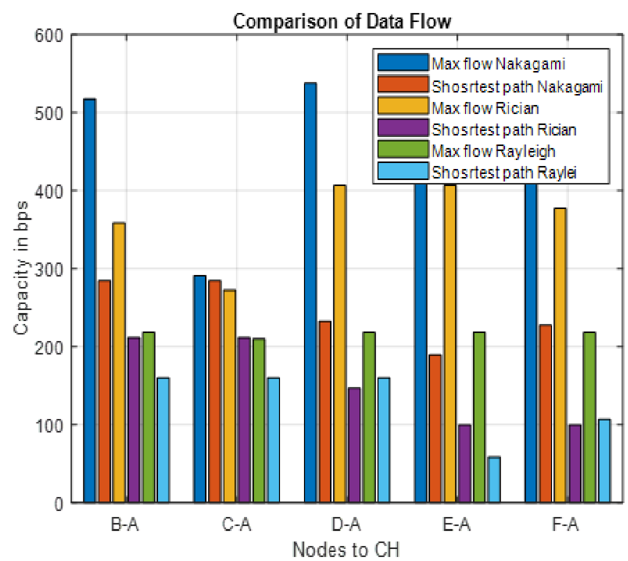


(a) Nodes *B* to *J*

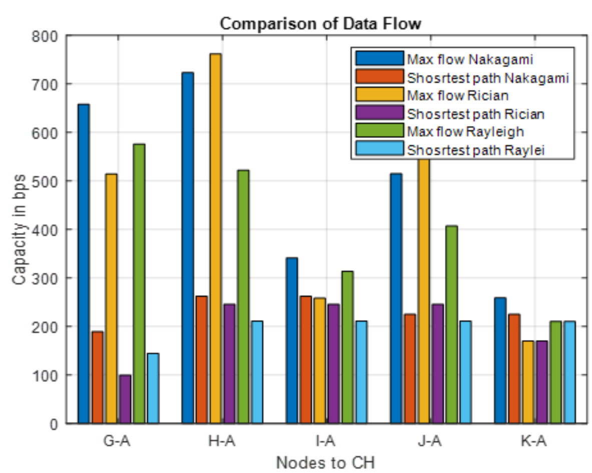


(b) Nodes *K* to *S*

Figure 10 Comparison of Energy Factor



(a) Nodes *B* to *F*



(b) Nodes *G* to *K*

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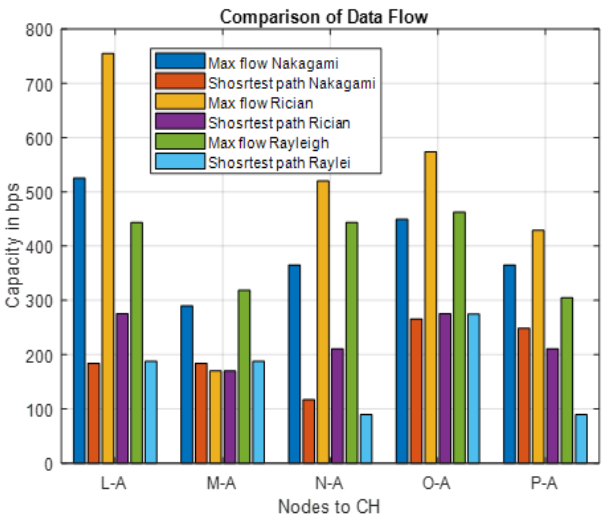
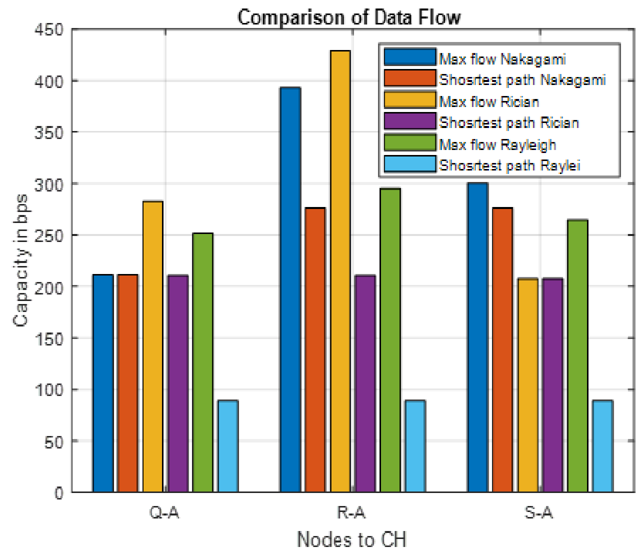


(c) Nodes *L* to *P*



(d) Nodes *Q* to *S*

Figure 11 Comparison of Dataflow of Three Different Fading Channels (Average SNR = 3dB)

Table 5 Comparison of Nakagami-*m*, Rician, and Rayleigh Fading

Experiment	Max flow of Nakagami-*m* (bps)	OSPF of Nakagami-*m* (bps)	Max flow of Rician (bps)	OSPF of Rician (bps)	Max flow of Rayleigh (bps)	OSPF of Rayleigh (bps)
1	431.5333	230.2254	414.5896	196.9695	327.4699	151.5808
2	426.6446	196.7572	368.5130	192.1817	329.8247	154.9249
3	350.4279	181.1879	348.9750	167.1210	346.6127	134.9656
4	428.8859	214.0186	399.4345	200.8584	316.0122	158.9821
5	401.4673	200.6905	353.6450	182.5446	275.9198	114.7757

Next, three types of wireless fading channels: Nakagami-*m*, Rician, and Rayleigh fading are considered in WSN under the concept of [41-42]. Taking SNR of $10\log_{10}(2)$ dB, the evaluated data rate under six combinations of fading and data flow algorithms and the corresponding results are shown in the bar graph of Figure 11. The flow is found maximum for Nakagami-*m* fading, a little bit lower for Rican fading, and the lowest for Rayleigh fading case. The mean flow is shown in Table 5 running the simulation five times.

Here Nakagami-*m* provides the best result since the channel model has *m* different weak links, next one is the Rician model which has one strong link between source and destination and finally Rayleigh shows the worst result since there is no Line of Sight (LOS) path between source and destination.

Therefore, under the steady state condition of WSN (after the formation of the cluster), the data rate and energy consumption per node from member nodes to CH depends on (i) the topology of the network (ii) the fading condition of the channel and (iii) algorithm of data flow. The entire work of the paper is independent of the cluster-forming algorithm and application layer of the network.

6. CONCLUSION

This paper deals with throughput and energy per node of WSN using two dataflow algorithms under three small-scale fading environments. The Max flow algorithm provides better results in the context of channel capacity at the expense of the complexity of the algorithm, involvement of more links, and sensor nodes. The Nakagami-*m* fading environment provides the best results among the three fading channels because *m* weak links between source and destination. Still, there is a scope to apply the channel model of mm waves (near 30 GHz) of 5G/6G under hostile environments like foggy and rainy weather. Then experiments of the paper can again be applied on mm waves to see how much difference appears against capacity and energy per node under these two algorithms. In

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the future point-to-point traffic model of a network will be converted to the equivalent multi-hop wireless link of [43] to evaluate the performance of WSN. The impact of scalability on the performance of the network will be considered in the future. The main limitation of the paper is that it ignores the mobility and failure of a sensing node.

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