Randomness Assists in Wireless Connectivity

Sumit Kumar[1], *IEEE, Member*, Taniya Singh[1],
Mohammad Akhlaqur Rahman[2], Rajib Kumar Jha[2], *IEEE, Senior Member*
[1]Indian Institute of Information Technology Una
[2] Indian Institute of Technology Patna
Email:(sumitphd13, singhtaniya1998, rahman.iitp, jharajib)@gmail.com

***Abstract*—In a larger area with less number of deployed nodes, to localize the event such as the location of the fire in a forest, the transmission range (TR) of different nodes plays a crucial role. Here, this study demonstrates a method to increase the transmission range (TR) using the benefits of randomness. With the mathematical expression, we have shown how randomness can benefit us. The increment in σ causes an average increase in the transmission range. This increment in transmission range causes a high probability of connection $C(r)$ between two remote nodes. According to the event, some of the nodes can be placed in an area for the detection of the exact location of the fire. It can be possible that either some of the nodes positioned at the precise location or can be some meters away. We are assuming the case of nodes placed at a distance from the location of the fire. The reflected signal which will be received by the transmitting node from the destination will of lower strength and hence it won't be possible for us to detect the exact location. For increasing the exactness of the location, we can introduce disturbance between the two distinct nodes which in turn creates more randomness due to the multiple reflections.**

***Index Terms*—Wireless network, Link connectivity, Transmission range.**

I. Introduction

With the rapid development of the internet, energy consumption plays a crucial problem in the wireless industry [1]. The data volume of wireless networks is expected to increase by a factor of ten every five years, which is associated with an increase in energy consumption of 16-20%, according to statistics. By applying this rate to mobile communications, it will contribute 15-20% of the total energy consumption of Information and Communications Technologies (ICT) [2]. With the advancement in multimedia technology, video or image [3]–[7] also needs to be communicated over wireless network

The wireless industry faces a sustainable development in these coming years. However, the issues of connectivity decide the performance of the wireless network system when the channel is dynamic. In the context of wireless communications, universal accepted service is the connectivity *i.e.,* nodes must have high coverage range. In the remote or hilly area, the coverage plays a significant role to give the internet service to the customers. The deployment of nodes for many different applications such as forest fire monitoring and detection of faulty nodes, agriculture *etc.,* is done to have a higher probability of connection (C) [8].

At the same time, the study of noise or random behavior of channel has to be taken care of. We always assume that the noise deteriorates the performance of the system. However, this statement is not valid in general. Benzi *et al.* [9] originally suggested the concept of stochastic resonance (SR), which describes a curious nonlinear physical phenomenon in a bistable system that is subjected to periodic and random forcing: an increase in input noise can lead to an improvement in the signal-to-noise ratio of output. Different applications such as weak signal detection using the use of external noise have been shown in the papers [5], [10]–[14].

The primary application nowadays is a point to point communication. The wired connection costs much higher than wireless transmission. There are important applications where sensor nodes are used to find out the location of the moving nodes. For example, we need to find out the exact location of the fire in a forest; we need to deploy the sensor nodes in the forest.

Wireless sensor networks may comprise of numerous different types of sensors like low sampling rate, seismic, magnetic, thermal, visual, infrared, radar, and acoustic, which are intelligent to monitor a wide range of ambient situations. Sensor nodes are used for constant sensing, event ID, event detection & local control of actuators [15]. The applications of wireless sensor network mainly include health, military, environmental, home, & other commercial areas. In Fig. 1, we have shown how the nodes are distributed in a channel. The channel keeps on varying as the nodes move on. Therefore, it is quite challenging to get high connectivity in the wireless sensor network.

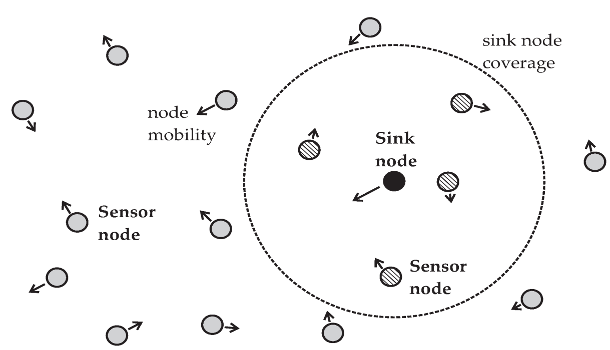

Fig. 1: Wireless connectivity with different nodes. The connectivity is a random process. Node mobility represents those nodes which can move in any direction. With respect to a sink node, we have encircled a sink node coverage.

Structure of the paper: Section II discusses the basic concepts of communication models. In Section III, we describe the outcomes of the proposed study. In Section IV, we describe the conclusion of the proposed study.

II. Different Communication Models

A link is a transmitting medium between a sender and transmitter node [16]. There are different models with which communication between sender and transmitter takes place. In the absence of any disturbance or interference, we always assume that the receiver node is connected with the transmitter. Let us assume that the transmitter transmits the power P_t. Assume the L as channel attenuation or power loss. Then, the received power can be written as $P_r = P_t - L$. If the $L < L_{th}$, then a direct radio link between nodes can exist, where $L_{th} = P_t - P_{r_{min}}$ with $P_{r_{min}}$ stands for minimum power received by the receiver. Generally, for moving channel between a sender and a receiver, we use a different model for the study of the link. These are classified into different groups which are as follows.

A. Deterministic Model

This model is described by the following equation

$$L_0(r) = k_0 + k_1 \ln r, \tag{1}$$

where $L_0(r)$ stands for power loss at a distance r. k_0 and k_1 stand for the characteristics of the channel. Here, we assume that sender is located at the center of the disk of radius r_0. The transmission range (TR) is a constant and is given by

$$TR = r_0 = e^{\frac{L_{th} - k_0}{k_1}} \tag{2}$$

In the wireless channel, generally, the nodes keep on moving. Therefore, the channel variation can easily be seen. Thus, we need a variable transmission range rather than a constant transmission range.

B. Statistical Model

The randomness or stochastic nature of the wireless channel enforces us to have variable transmission range to have proper connectivity. Here, we discuss the benefits of the channel randomness and how does this improve the connectivity.

$$L = k_0 + k_1 \ln r + S, \tag{3}$$

where S is called a shadowing sample which is assumed as Gaussian distributed with zero mean and standard deviation σ. The corresponding transmission range (TR) can be given as

$$TR = e^{\frac{L_{th} - k_0 - s}{k_1}}, \tag{4}$$

where s denotes the Gaussian distributed random variable.

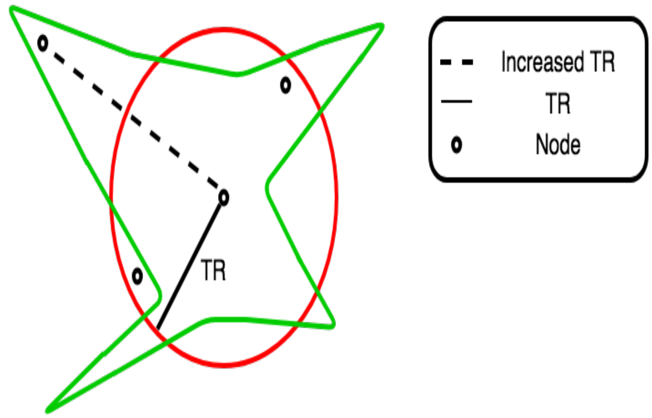

Fig. 2: (Red) shows the deterministic channel where (Green) shows the stochastic channel.

C. Probability of link connection

Here, we derive the expression for the probability of link connection $C(r)$. The probaility that the two nodes are connected when the path loss is lesser than a predefined L_{th} *i.e.,* $L \leq L_{th}$ [17].

$$C(r) = P\left(L \leq L_{th}\right) = P\left(S \leq L_{th} - L_0(r)\right) \tag{5}$$

$$C(r) = 1 - \frac{1}{2} erfc\left(\frac{L_{th} - k_0 - k_1 \ln(r)}{\sqrt{2}\sigma_{new}}\right), \tag{6}$$

where erfc(.) is complementary error function. After simplification, it can be written as follows.

$$C(r) = Q\left(\frac{L_{th} - k_0 - k_1 \ln(r)}{\sigma_{new}}\right), \tag{7}$$

where σ_{new} can be given as follows.

$$\sigma_{new} = \sqrt{\sigma^2 + \sigma_{ext}^2}, \tag{8}$$

where σ_{ext}^2 is the variance of externally added noise. k_0 and k_1 show the parameters of the medium or channel. Q represents the complementary cumulative distribution function (CCDF). Using this model, we can derive the expression for the disk model when $\sigma = 0$ *i.e.,* when $\sigma = 0$, the random variable s becomes 0. In that case,

$$C(r) = \begin{cases} 1, & r \leq r_0 \\ 0, & otherwise. \end{cases} \tag{9}$$

where r_0 is the transmission range (TR). It can be easily seen that the randomness increases the transmission range. This increment in transmission range causes certain nodes audible which are not reachable when adopting the disk model ($\sigma = 0$) because they are outside the circumference having radius TR. However, sometimes, it makes non-audible some nodes which are inside the circumference. It can be seen in Fig. 2

For any particular application, nodes are deployed in such a way that it can achieve the task of fetching information [18]. Assume that nodes are spatially distributed according to the

Poisson point process (PPP) with density ρ. Let us assume that μ represents the average number of neighbors the sink.

$$\mu_{new} = \begin{cases} 2\rho r_0 e^{\frac{\sigma_{new}^2}{2k_1^2}} & for \quad d = 1 \\ \pi \rho r_0^2 e^{\frac{2\sigma_{new}^2}{k_1^2}} & for \quad d = 2 \\ \frac{4\pi}{3}\rho r_0^3 e^{\frac{9\sigma_{new}^2}{2k_1^2}} & for \quad d = 3 \end{cases} \tag{10}$$

where r_0 can be given by $r_0 = e^{\frac{L_{th}-k_0}{k_1}}$ and d represents the dimension. The μ_{new} becomes μ when σ_{new} becomes σ. σ_{new} increases as σ_{ext} increases. The expression of μ can be written as follows.

$$\mu = \begin{cases} 2\rho r_0 e^{\frac{\sigma^2}{2k_1^2}} & for \quad d = 1 \\ \pi \rho r_0^2 e^{\frac{2\sigma^2}{k_1^2}} & for \quad d = 2 \\ \frac{4\pi}{3}\rho r_0^3 e^{\frac{9\sigma^2}{2k_1^2}} & for \quad d = 3 \end{cases} \tag{11}$$

It suggests that noise is actually beneficial to the wireless system in terms of its connectivity. The percentage change in the μ is given by

$$I = \frac{\mu_{new} - \mu}{\mu}. \tag{12}$$

Solving for I

$$I = \begin{cases} e^{\frac{\sigma_{ext}^2}{2k_1^2}} - 1 & for \quad d = 1 \\ e^{\frac{2\sigma_{ext}^2}{k_1^2}} - 1 & for \quad d = 2 \\ e^{\frac{9\sigma_{ext}^2}{2k_1^2}} - 1 & for \quad d = 3 \end{cases} \tag{13}$$

When $\sigma_{ext} = 0$, then $I = 0$. However, Eq. 13 shows the increment in μ.

III. Discussion

Here, in this section, we discuss the result and effects of randomness in the connectivity. When $\sigma = 0$, the statistical model behaves as the deterministic model. However, the major drawback about the deterministic model is that its transmission range. The effect of randomness produces a high transmission range. It gives a high probability of connection, C. Fig. 3 shows the probability of connection as σ is increased.

Also, an increase in μ causes the increment in the average number of the neighboring sink. It has been shown in Fig. 4.

IV. Conclusion and Future Work

This report gives a brief idea about the utilization of external noise or randomness in the wireless sensor network to increase the probability of connection. It also helps in detecting the nodes which are not audible in case of the deterministic model. Furthermore, the results suggest that incrementing the variance by adding σ_{ext} gives exponential increment in the audible nodes as far as $d = 3$ is concerned. It opens a gateway to the researchers for the deployment of the sensor nodes for increased connectivity.

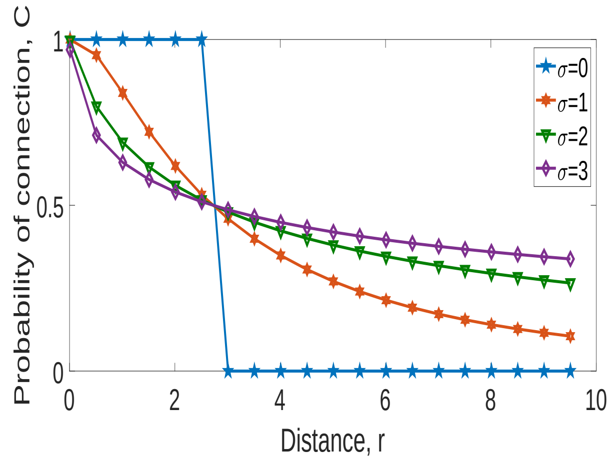

Fig. 3: Wireless connectivity with different shadowing values.

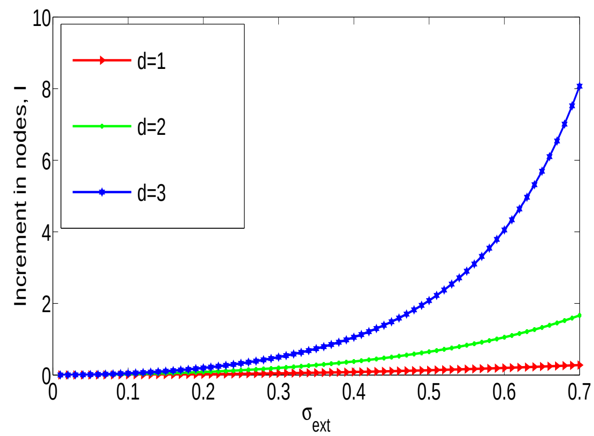

Fig. 4: Increment in audible nodes. Here, d represents the dimension such as line (d=1), area (d=2) and volume (d=3).

Acknowledgment

We thank the Ministry of Electronics & Information Technology, Government of India (Digital India Corporation (Grant No.U72900MH2001NPL133410)) for granting fund to this prestigious project in the Signal & Image Processing Laboratory at Indian Institute of Technology Patna, India.

References

[1] M. J. Grubb, "Communication energy efficiency and economic fallacies," *Energy Policy*, vol. 18, no. 8, pp. 783–785, 1990.

[2] L. Cheng, T. Yu, H. Jiang, S. Shi, Z. Tan, and Z. Zhang, "Energy internet access equipment integrating cyber-physical systems: Concepts, key technologies, system development, and application prospects," *IEEE Access*, vol. 7, pp. 23 127–23 148, 2019.

[3] S. Kumar and R. K. Jha, "Enhancement of high dynamic range images using variational calculus regularizer with stochastic resonance," in *Proceedings of the Tenth Indian Conference on Computer Vision, Graphics and Image Processing*. ACM, 2016, p. 38.

[4] S. Shourya, S. Kumar, and R. K. Jha, "Adaptive fractional differential approach to enhance underwater images," in *Embedded Computing and System Design (ISED), 2016 Sixth International Symposium on*. IEEE, 2016, pp. 56–60.

[5] S. Kumar and R. K. Jha, "Noise-induced resonance and particle swarm optimization-based weak signal detection," *Circuits, Systems, and Signal Processing*, pp. 1–26, 2018.

[6] B. Panna, S. Kumar, and R. K. Jha, "Image encryption based on block-wise fractional fourier transform with wavelet transform," *IETE Technical Review*, pp. 1–14, 2018.

[7] S. Kumar and R. K. Jha, "A fractional integrator based novel detector for weak signal detection with watermark application," in *2018 Asia-Pacific Signal and Information Processing Association Annual Summit and Conference (APSIPA ASC)*. IEEE, 2018, pp. 1791–1795.

[8] W. Y. Poe and J. B. Schmitt, "Node deployment in large wireless sensor networks: coverage, energy consumption, and worst-case delay," in *Asian Internet Engineering Conference*. ACM, 2009, pp. 77–84.

[9] R. Benzi, A. Sutera, and A. Vulpiani, "The mechanism of stochastic resonance," *Journal of Physics A: mathematical and general*, vol. 14, no. 11, p. L453, 1981.

[10] S. Kumar and R. K. Jha, "Weak signal detection from noisy signal using stochastic resonance with particle swarm optimization technique," in *Noise and Fluctuations (ICNF), 2017 International Conference on*. IEEE, 2017, pp. 1–4.

[11] S. Kumar and A. K. R. K. Jha, "Performance analysis of segmentation using ssr under different noise conditions," in *Noise and Fluctuations (ICNF), 2017 International Conference on*. IEEE, 2017, pp. 1–4.

[12] S. Kumar, R. K. Jha *et al.*, "Characterization of supra-threshold stochastic resonance for uniform distributed signal with laplacian and gaussian noise," in *Noise and Fluctuations (ICNF), 2017 International Conference on*. IEEE, 2017, pp. 1–4.

[13] S. Kumar and R. K. Jha, "Weak signal detection using stochastic resonance with approximated fractional integrator," *Circuits, Systems, and Signal Processing*, vol. 38, no. 3, pp. 1157–1178, 2019.

[14] S. Kumar, A. Kumar, and R. K. Jha, "A novel noise-enhanced back-propagation technique for weak signal detection in neyman–pearson framework," *Neural Processing Letters*, pp. 1–18, 2019.

[15] M. Hefeeda and H. Ahmadi, "A probabilistic coverage protocol for wireless sensor networks," in *2007 IEEE International Conference on Network Protocols*. IEEE, 2007, pp. 41–50.

[16] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, "Wireless sensor networks: a survey," *Computer networks*, vol. 38, no. 4, pp. 393–422, 2002.

[17] A. Ribeiro and G. B. Giannakis, "Bandwidth-constrained distributed estimation for wireless sensor networks-part ii: unknown probability density function," *IEEE Transactions on Signal Processing*, vol. 54, no. 7, pp. 2784–2796, 2006.

[18] R. Verdone, D. Dardari, G. Mazzini, and A. Conti, *Wireless sensor and actuator networks: technologies, analysis and design*. Academic Press, 2010.