Impact of Channel Capacity and Signal Bandwidth on Power Consumption in New Generation Wireless Networks

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***Abstract:*-Nowadays, wireless communication has become an important aspect in almost every sphere of life. As wireless devices are battery-constrained, energy competency is an important issue in analyzing the performance of wireless networks. With the advent of Green Networking, energy efficient mechanisms are need of hour. Channel capacity and signal bandwidth are two of the important factors that can affect the energy levels of the wireless devices especially during handover. This paper presented the effect of channel capacity and signal bandwidth on power consumption of wireless devices during vertical handoff. Handover simulation between Wi-Fi and WiMAX technology was implemented for two sets of nodes namely Type-I and Type-II nodes. Evaluation of power consumption was made at three different voltage levels i.e. charge voltage, nominal voltage and cut-off voltage. The performance of network was measured in terms of throughput, Packet Delivery Ratio and residual energy levels of the nodes. The results of the study can provide a roadmap to the novel researchers for devising energy efficient handoff mechanisms to enhance the performance of wireless networks.**

***Keywords:*-Channel capacity, Channel bandwidth, Signal bandwidth, Power consumption, Residual energy, Throughput and Packet Delivery Ratio.**

I. Introduction

With every generation, wireless networking is turning out to be an essential part of humans' life. In present times faster communication and seamless connectivity is the call of the hours. Quality of Service (QoS) and Quality of Experience (QoE) standards are prominent measures in deciding the performance of wireless networks. Handover is a stage of service transition either between same technological standards or among different technological standards. Since, wireless devices are battery operated, they are highly energy constrained and therefore attaining desired QoS and QoE standards is an intricate affair. This has led to the proliferation of Green Networking, to enhance energy efficiency of wireless devices and devising energy efficient mechanisms resulting in high performance wireless networks especially during handover scenario.

Handover [1] can be greatly affected by various factors like mobility, signal strength variations, noise levels and interference, scalability factors etc. Amongst them, channel capacity and signal bandwidth are prominent factors which affect the energy levels of wireless nodes to a great extent. Channel capacity can be defined as the maximum data rate at which data can be transferred over the given communication channel. However, Channel bandwidth is the allowable rate of data transfer over the channel without the loss of energy. Similarly, Signal bandwidth can be defined as the actual rate at which signals are being transmitted over the channel and it highly depends on the configuration of the transmitter.

In context of Green Networking and energy efficiency, this paper analyzed the effect of variations in channel capacity and signal bandwidth on power consumption of wireless nodes and further on the performance of the wireless networks. This study can facilitate the invention of novel energy efficient mechanisms for boosting up the overall performance of wireless networks in power constrained environment. The rest of the paper is organized as the importance of channel capacity in new generation wireless networking was discussed in Section 2 followed by the power consumption calculations due to variation in channel capacity and signal bandwidth in Section 3. Section 4 presented the experimental setup under which the simulation was carried out. The results obtained in the study were briefly discussed in Section 5. Finally conclusions drawn from the study were discussed in Section 6.

II. SIGNIFICANCE OF CHANNEL CAPACITY IN NEW GENERATION WIRELESS NETWORK

New Generation Wireless Networks (NGWNs) favor low latency applications to achieve better QoS standards. Therefore, to enhance performance of low latency applications in terms of QoS standards, [2] presented a survey on various techniques based on Effective Channel (EC), a QoS-aware link layered channel model over different networks, explored EC operations for different designs and architectural requirements, performed EC analysis for delay sensitive applications and offered future directions towards EC maximization. For effective utilization of channel, complete knowledge about channel must be available to the sender and receiver. To justify the importance of channel knowledge, a model for time varying communication over single access and multiple access channels is presented in [3] which applied Gauss-Markov process to contrast rate of time variation to the loss of information due to imperfect knowledge about the channel.

Noise plays important role in the performance of wireless networks. It can hamper maximum utilization of channel capacity. To define the impact of noise over Additive White Gaussian Noise (AWGN), [4] presented a study to illustrate the application of Shannon Hartley Theorem for data streams and sparse recovery. Similarly for determining the capacity of sampled Gaussian channels, sampling theory and information theory can overlapped to determine the impact of sampling on the capacity of channels and how to maximize capacity using sampling techniques. Regarding this, [5] derived the capacity of sampled analog channels under different sampling techniques. The study analyzed the interrelation between under sampled channels and Multiple-Input Multiple-Output (MIMO) channels and also between under sampled channels and mean-squared error (MSE) estimation from sampled data. The results explained the impact of sub-Nyquist sampling techniques on channel capacity and illustrated the tradeoff between information rate and sampling rate. Similarly, [6] examined the performance of linear time-invariant Gaussian channel under the impact of sub-Nyquist non uniform sampling with the channel knowledge accessible at receiver and sender end. The result showed that the sampling configuration extracted out frequencies of highest Signal-to-Noise Ratio and that non uniform sampling sets or scrambling of spectral components does not provide capacity gain.

For better utilization of channel capacity, the architecture and design of antenna is an important factor. In this regard, to build appropriate multi-antenna systems for wireless communication systems,[7] provided capacity expression and information rate limits for different structure various fading models and discussed system design complexities and practical limitations for each architecture. Wireless communications occur over electromagnetic spectrum which is inherently limited and scarce in terms of range. This results in finite capacity of wireless networks. In this context, [8] presented a brief survey over techniques for maximizing spectrum efficiency which will in turn enhance the channel capacity of wireless networks.

Network performance is also affected greatly for indoor environments due to the bandwidth limitations. To cope up with this, indoor Optical Wireless Communication Systems (OWCS) were introduced, but the performance is still

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affected by spatial variations in communication parameters owing to receiver mobility. Therefore, [9] presented a behavioral analysis of these communication parameters over system performance with respect to receiver mobility in indoor OWCS.

Energy efficiency plays a vital role in functioning of new generation wireless networks since wireless devices are battery powered. This has led to the proliferation of Green Networking era. The increase in power consumption of wireless devices causes considerable degradation in channel capacity. Power consumption of nodes depends on various factors like mobility, signal strength variations, scalability channel capacity etc.[10] presented a study on the various energy efficient mechanisms in wireless networking. Moreover, characterization of consumed power is quite challenging under dynamic networking conditions. In this regard, [11][12] presented a controlled environment for characterizing the energy consumption of nodes due to various factors affecting the power levels of wireless nodes. Similarly, [13] discussed the effect of mobility over power consumption of wireless nodes. In addition to transmission energy of nodes, the processing energy i.e. the energy when the transmitter is idle but in active mode affects the channel capacity of the network as well. For this, [14] presented an analysis of impact of processing energy over bursty transmission in low (Signal to Noise Ratio) SNR regime. Ad hoc networks possess various challenges like varying channel capacity, higher error rates, limited power supply etc. To overcome this, [15] proposed a collision-free power and spectrum efficient system by combining Code Division Multiple Access (CDMA) technique with Spread Spectrum (SS) technique. Results showed that the proposed system reduced the latency by 75% and power consumption by 15% thereby providing higher bandwidths and low latency communications over the network.

Power Consumption and Bandwidth efficiency are highly interdependent. To study this interdependency, [16] analyzed a tradeoff between energy efficiency and bandwidth efficiency of nodes in ad hoc wireless networks for half duplex multi hop scenario using common power and common rate schemes and combined both energy and bandwidth efficiency into single metric for analyzing the transport efficiency. Results showed that the bandwidth efficiency was higher for common rate schemes whereas energy efficiency was dependent on SNR levels. Similarly, [17] analyzed tradeoff between power efficiency and bandwidth efficiency and conducted top down analysis of commercial wireless network to evaluate optimization criteria for the two efficiency parameters. The study also discussed the challenges of resource management and its effect on the overall system efficiency.

In present times, higher data rates are needed at lower energy loss. This demands the establishment of bandwidth intensive applications based on millimeter-wave and sub-THz carrier frequency spectrum. Regarding this, [18] performed consumption factor analysis using frequency domain representations to analyze the effect of channel characteristics on data rate and energy consumption of the network having less than 1 km cell radii. The results of the study demonstrated the effect of attenuation over power efficiency of millimeter-wave based channels. It also established the use of millimeter-wave frequencies for higher bandwidth in future networking standards.

Signal bandwidth and signal power are the two important factors affecting the performance of wireless networks. Both these factors are limited and have certain challenges in terms of utilization. In this context, [19] presented a brief review about energy efficient techniques for enhancing bandwidth utilization and also discussed the underlying limitations of the existing techniques. To enhance energy efficiency and bandwidth, [20] proposed a resource

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allocation for heterogeneous small cell networks. An optimal iterative algorithm and a suboptimal low complexity algorithm were designed for resource allocation and power efficient network design respectively by allocating transmission energy and bandwidth for backhauling. Comparison of proposed scheme with existing schemes was also drawn.

III. Power Consumption due to Variations in Channel Capacity

Wireless nodes are battery powered and therefore their energy levels can be greatly affected due to the variations in the channel capacity of wireless network which in turn affects the network performance. On the basis of presence of noise, channels can be classified as either noiseless or noisy. The evaluation of energy usage of wireless nodes due to varying channel capacity and signal bandwidth is illustrated as given below.

A. Power Consumption in Noiseless Channel

When the effect of random influences is negligible and there are no random errors or disturbances during wireless communication, the channel is assumed to be noiseless. Under such conditions, for a data which is being represented using L signal levels, the relation between channel capacity (C) measured in bits per second (bps) and signal bandwidth (SB) measured in Hertz (Hz) is expressed by Nyquist Theorem[21][22] as stated in Equation 1.

$$C = 2\times SB\times \log_2 (L) \tag{1}$$

If the size of data packet is n bytes and t_x is the transmission power in watts for one packet, then the total power consumed (P_1) in watts for transmission of one bit over the channel can be calculated as given in Equation 2.

$$P_1 = \frac{n\times 8}{t_x} \tag{2}$$

For a given signal bandwidth (SB) in bits per second (bps), the total data (D_{total}) transmitted over the channel in a time period of T seconds and the power consumed (P_{BW}) in watts for transmitting D_{total} bits can be calculated as shown in Equation 3 and Equation 4.

$$D_{total} = T \times SB \tag{3}$$

$$P_{BW} = P_1 \times D_{total} \tag{4}$$

At a given voltage (V) in volts, the power consumed (P_{BW}) in watts is then calibrated into equivalent power (P_{BWh}) in Watt-hour (Wh) and equivalent power (P_{BAh}) in Ampere-hour (Ah) according to Equation 5 and Equation 6.

$$P_{BWh} = (P_{BW} \times \mathrm{T})/3600 \tag{5}$$

$$P_{BAh} = P_{BWh} \,/\, \mathrm{V} \tag{6}$$

B. Power Consumption in Noisy Channel

Considering the effect of noise in wireless networking, the relation between channel capacity (C) in bits per second and signal bandwidth (SB) in Hertz at a given Signal-to-Noise Ratio (SNR) can be calculated according to Shannon Hartley Theorem[23][24]as given in Equation 7.

$$C = SB\times \log_2 (1+SNR) \tag{7}$$

Signal-to-Noise ratio can be expressed as ratio of signal power (S) in Watts and noise power (N) in Watts and therefore, the above equation can be expressed in terms of power consumed by the wireless nodes as shown in Equation 8 below.

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$$C = SB \times \log_2 (1+\frac{S}{N}) \tag{8}$$

To consider different scenario causing noise in channel during wireless communications, for a given noise density i.e noise power per unit of bandwidth (N_0) in Watts/Hertz and signal power (P_s) in watts, Equation 8 can be redefined according to Additive White Guassian Noise (AWGN) model and is represented as Equation 9.

$$C = SB \times \log_2 (1+\frac{P_S}{N_0 \times SB}) \tag{9}$$

According to Shannon Hartley Theorem, when SNR becomes negative, the channel capacity becomes linear with respect to the bandwidth and logarithmic with respect to the power factor. This region is known as Bandwidth limited regime represented mathematically as given in Equation 10.

$$C \approx SB \times \log_2 (\frac{P_S}{N_0 \times SB}) \tag{10}$$

Similarly, when the SNR becomes positive, the channel capacity becomes insensitive to bandwidth and linear to the power factor. This region is known as Power limited regime as represented in Equation 11.

$$C \approx (\frac{P_S}{N_0 \times SB}) \log_2 e \tag{11}$$

To calculate the overall power consumed by the wireless nodes due to the variation in channel capacity and signal bandwidth, the signal power (Ps) in watts can be calibrated into equivalent power P_{SWh}(in Watt-hour) and P_{SAh} (in Ampere-hour) for given time period (T) in seconds and voltage (V) in volts as given in Equation 12 and Equation 13.

$$P_{SWh} = (P_S \times T)/3600 \tag{12}$$

$$P_{SAh} = P_{SWh} \, / \, V \tag{13}$$

C. Cumulative Power Consumption in Noisy Channel

In noiseless channels, power consumption in watts due to signal bandwidth and channel capacity variations can be calculated individually under circumstances when signal bandwidth is lesser than channel capacity (P_{S1}) or under circumstances when signal bandwidth is equal to channel capacity (P_{S2}). To evaluate the overall power consumption of wireless nodes due to variation in channel capacity and signal bandwidth for noiseless channel, the average power ($P_{S(avg)}$)in watts can be calculated from the individual power (P_{Si}) for n iterations according to Equation 14 and Equation 15.

$$P_{S_i} = \frac{1}{2} \times \sum_{i=1}^{n} \left(P_{S_1} + P_{S_2}\right) \tag{14}$$

$$P_{S(avg)} = \frac{1}{n} \times \sum_{i=1}^{n} \left(P_{S_i}\right) \tag{15}$$

In view of the standard deviations, the standard power consumption $P_{S(std)}$(in watts) can be calculated according to Equation 16.

$$\text{Standard Energy } (P_{S(std)}) = \sqrt{\frac{1}{k-1} \times \sum_{i=1}^{k} (P_{S_i} - P_{S(avg)})^2} \tag{16}$$

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The average power consumption ($P_{S(avg)}$) can be calibrated to equivalent average power ($P_{SWh(avg)}$) in Watt-hour and equivalent average power ($P_{SAh(avg)}$) in Ampere-hour according to Equation 17 and Equation 18. The equivalent powers ($P_{SWh(avg)}$) and ($P_{SAh(avg)}$) can further be converted to standard values $P_{SWh(std)}$(in Watt-hour) and $P_{SAh(std)}$(in Ampere-hour) according to Equation 19 and Equation 20.

$$P_{SWh(avg)} = P_{S(avg)}/3600 \tag{17}$$

$$P_{SWh(std)} = P_{S(std)}/3600 \tag{18}$$

$$P_{SAh(avg)} = P_{SWh(avg)}/V \tag{19}$$

$$P_{SAh(std)} = P_{SWh(std)}/V \tag{20}$$

IV. EXPERIMENTAL SETUP

To study the impact of channel capacity and signal bandwidth on power consumption of wireless nodes and network performance, the simulation of vertical handover between IEEE 802.11n standards based WiFi network and IEEE 802.16 standards based WiMAX network was performed using Network Simulator (NS-2).Two wireless nodes were considered in the simulation namely Type-I node comprising 3.7 volt Li-ion battery of 3500 mAh power capacity and Type-II node comprising a 4 cell Li-ion battery of 14.8 volt and 3500 mAh power capacity. The simulation scenario is depicted in Figure 1 and the other specifications related to the simulation are described in Table 1. as follows :-

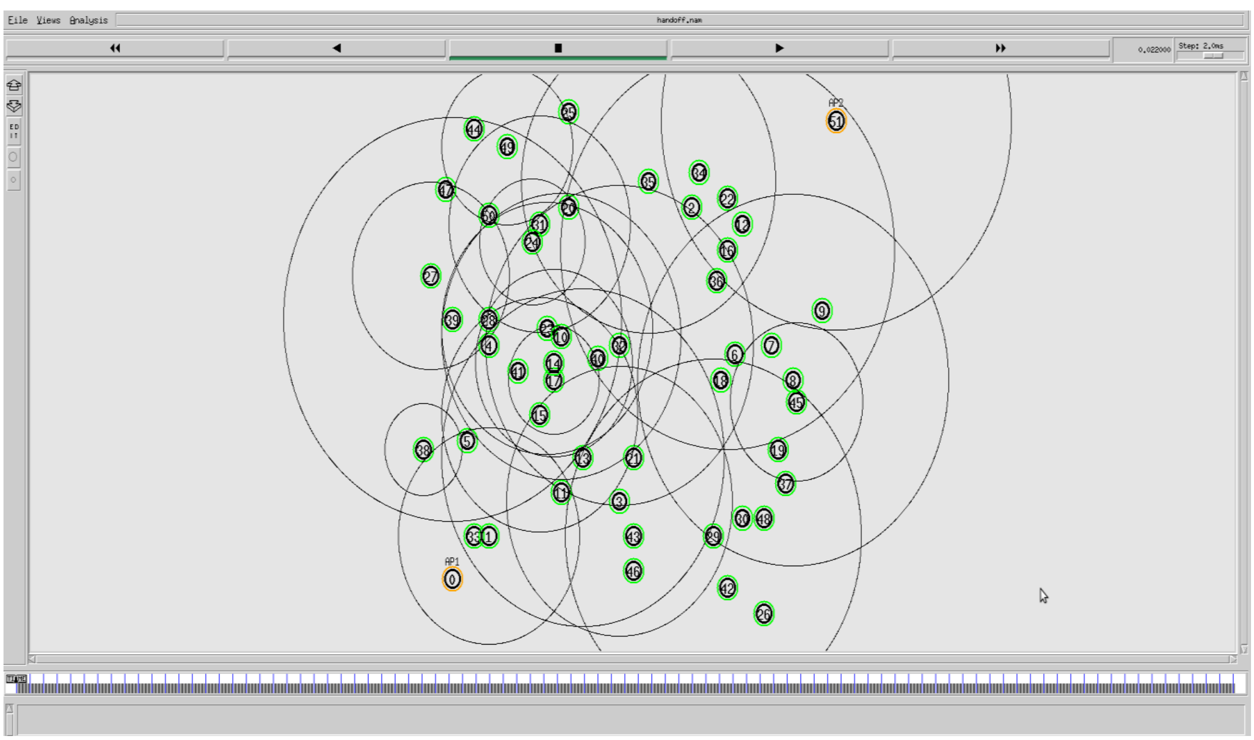


Figure.1. Simulation Scenario

TABLE I
SIMULATION PARAMETERS

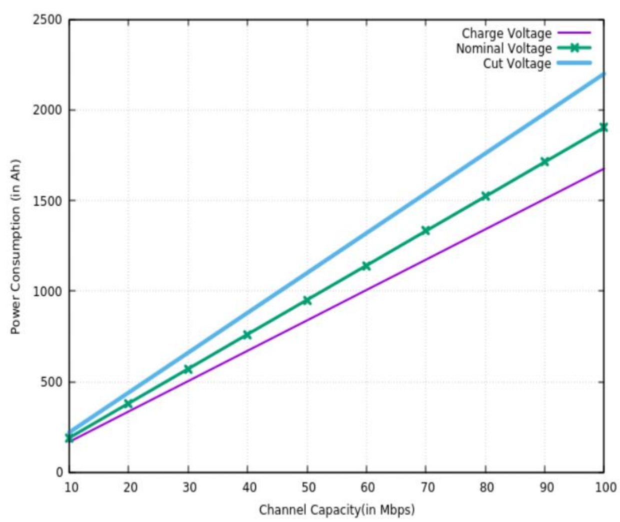
Configuration	Parametric Values
Simulation Area	600 * 600
Access Points	2
Number of Nodes	50
Propagation Model	Two Ray Ground
Traffic Type	CBR
Packet Size	1023 bytes
Channel Capacity	10-100 Mbps
Bandwidth	10-100 Mbps
Voltage Levels	4.2V, 3.7V and 3.2V

For implementing the initial energy levels of the wireless nodes, the simulation was carried out at three different voltage levels namely charge voltage representing the maximum energy levels, nominal voltage representing the average energy levels and cut-off voltage representing the lowest energy levels. The channel capacity and bandwidth of the channel varied in the range 10-100 Mbps at an increment of 10 Mbps per iteration.

V. RESULT ANALYSIS AND DISCUSSION

A. *Power Consumption*

The simulation results obtained in this study showed that for noiseless channels, the power consumed by wireless nodes increased as the channel capacity was increased for both Type-I and Type-II nodes. The average power consumed was found to be 921.6589862 Ah, 1046.207498 Ah and 1209.677419 Ah for Type-I nodes and 3686.635945 Ah, 4184.829991 Ah and 4838.709677 Ah for Type-II nodes respectively at charge, nominal and cut-off voltage respectively as shown in Figure 2.



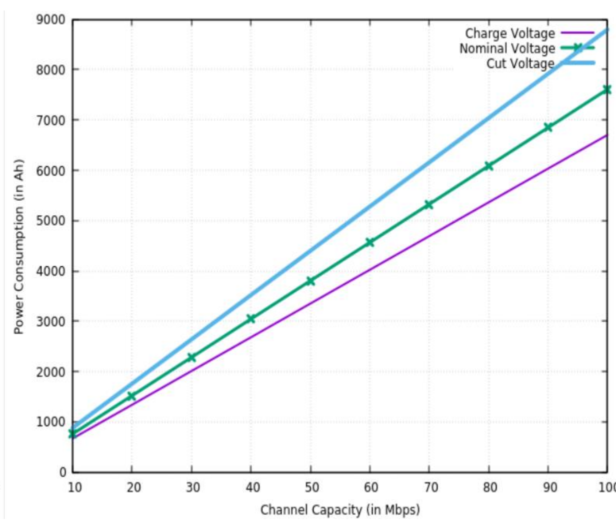


Figure.2. Variation of power consumption with channel capacity in noiseless channel. (a) For Type-I nodes. (b) For Type-II nodes

For noisy channel also, the power consumed by the wireless nodes was found to be increasing with increase in signal bandwidth. The signal bandwidth can be either less than or equal to the channel capacity. The simulation

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results showed that under circumstances when signal bandwidth (SB) is lesser than channel capacity (C), the average power consumption was 4.13874×10^{80} Ah, 4.69803×10^{80}Ah and 5.4321×10^{80}Ah and 1.6555×10^{81}Ah, 1.87921×10^{81} Ah and 2.17284×10^{81}Ah for Type-I and Type-II nodes respectively at charge, nominal and cut-off voltages respectively as represented in Figure 3.

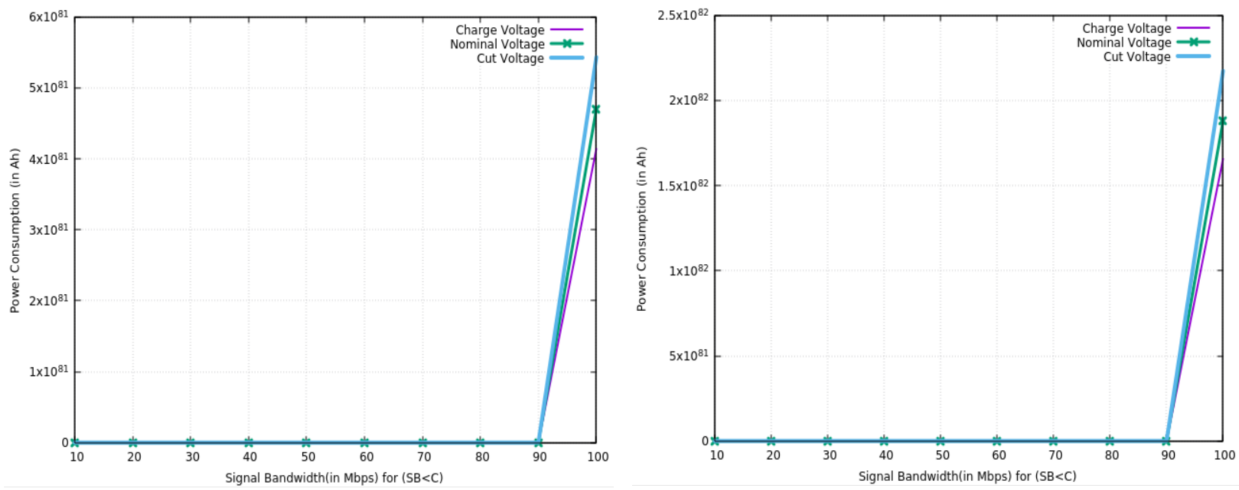

Figure.3. Variation of power consumption with signal bandwidth in noisy channel at SB<C. (a) For Type-I nodes. (b) For Type-II nodes

Similarly for noisy channels, when signal bandwidth (SB) is equal to the channel capacity (C), the average power consumption was 5.1014×10^{48} Ah, 5.79077×10^{48}Ah and 6.69558×10^{48} Ah for Type-I and 2.04056×10^{49} Ah, 2.31631×10^{49} Ah and 2.67823×10^{49} Ah for Type-II nodes at charge voltage, nominal voltage and cut-off voltage respectively as shown in Figure 4.

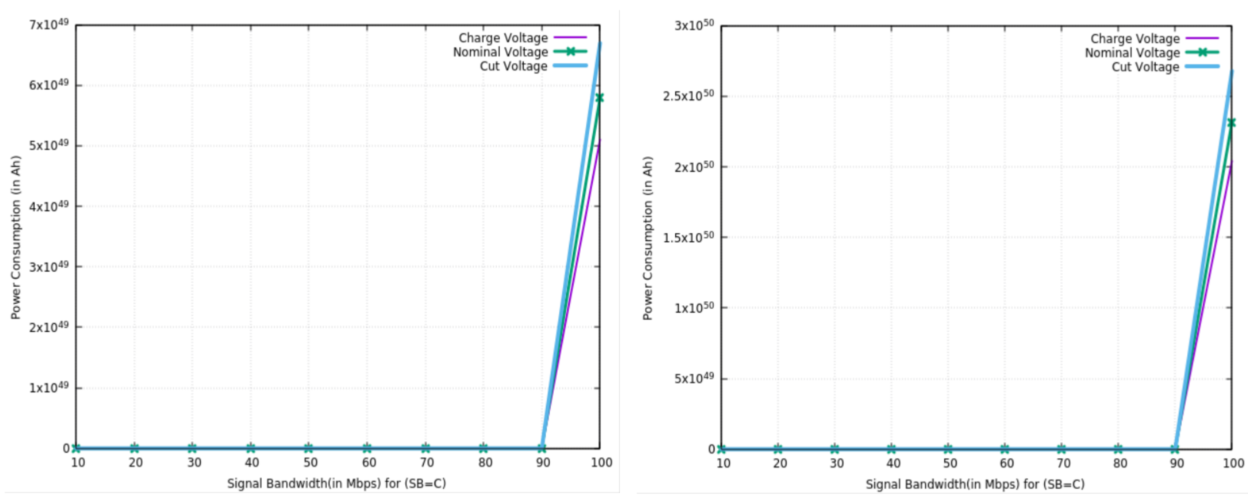

Figure.4. Variation of power consumption with signal bandwidth in noisy channel at SB=C. (a) For Type-I nodes. (b) For Type-II nodes

On combining the above mentioned two scenarios for noisy channels, the average cumulative power consumption for Type-I nodes was 2.06937×10^{80} Ah, 2.34901×10^{80} Ah and 2.71605×10^{80} Ah and 8.27748×10^{80} Ah, 9.39606×10^{80} Ah and 1.08642×10^{81} Ah for Type-II nodes at charge voltage, nominal voltage and cut-off voltage respectively as represented in Figure 5.

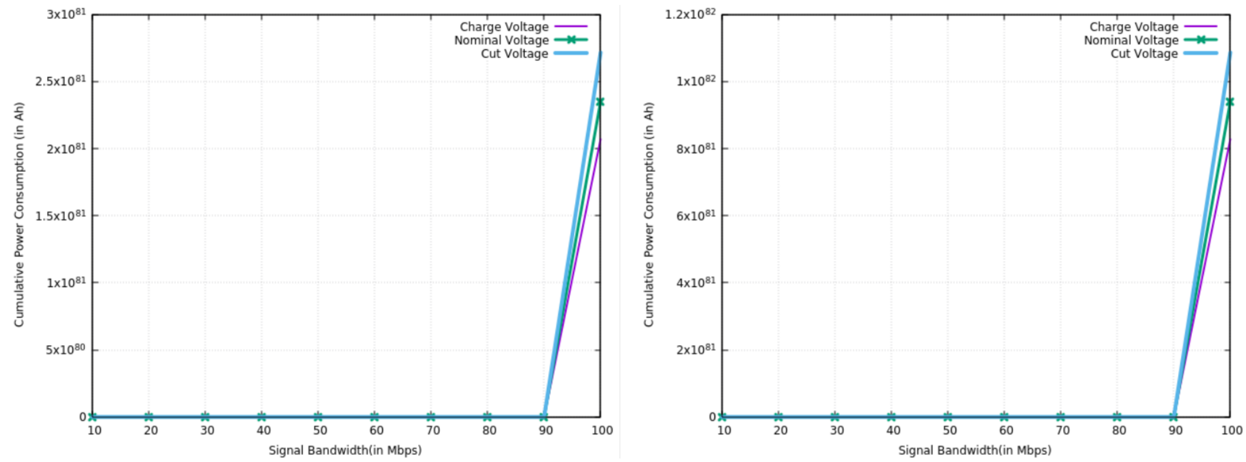

Figure.5. Variation of cumulative power consumption with signal bandwidth in noisy channel. (a) For Type-I nodes. (b) For Type-II nodes

B. *Residual Energy*

Contrary to the power consumption, the residual energy was found to be decreased as the channel capacity and the signal bandwidth increased. The average residual energy was calculated to be -918.1589862 Ah, -1042.707498 Ah and -1206.177419 Ah and for Type-I and -3672.635945Ah, -4170.829991 Ah and -4824.709677 Ah for Type-II nodes respectively at charge, nominal and cut-off voltages respectively in noiseless channel. The graphical representation of variation of residual energy with channel capacity for noiseless channel is represented in Figure 6.

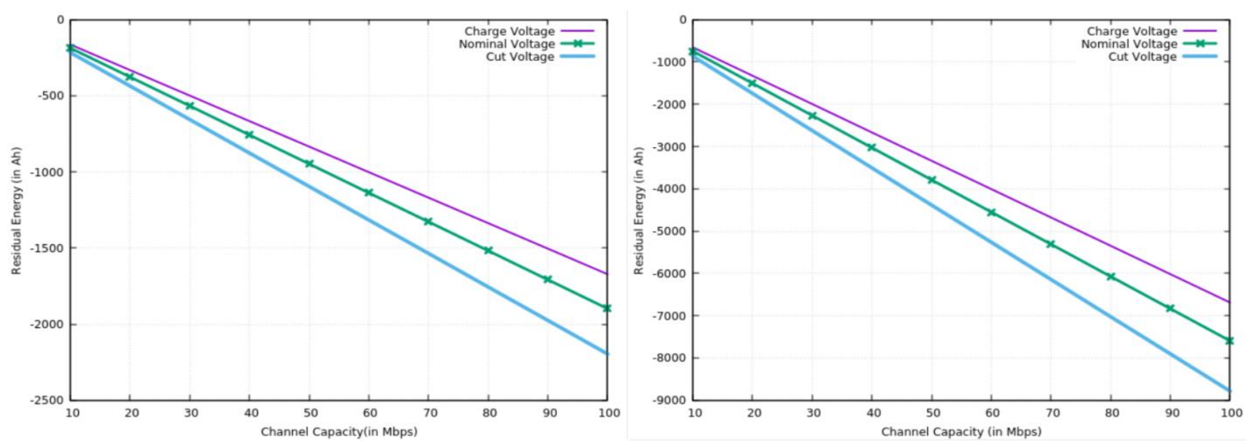

Figure.6. Variation of residual energy with channel capacity in noiseless channel. (a) For Type-I nodes. (b) For Type-II nodes

For noiseless channel, the average residual energy was found to be -4.13874×10^{80} Ah, -4.69803×10^{80} Ah and -5.4321×10^{80} Ah and -1.6555×10^{81} Ah, -1.87921×10^{81} Ah and -2.17284×10^{81} Ah for Type-I and Type-II nodes respectively at charge voltage, nominal voltage and cut-off voltage respectively when signal bandwidth was lesser than the channel capacity. Similarly, when signal bandwidth was equal to the channel capacity, the average residual energy was calculated to be -5.1014×10^{48} Ah, -5.79077×10^{48} Ah and -6.69558×10^{48} Ah for Type-I nodes and -2.04056×10^{49} Ah, -2.31631×10^{49} Ah and -2.67823×10^{49} Ah for Type-II nodes at charge voltage, nominal voltage and cut-off voltage respectively. The variation of residual energy with signal bandwidth for noisy channel is represented in Figure 7 and Figure 8.

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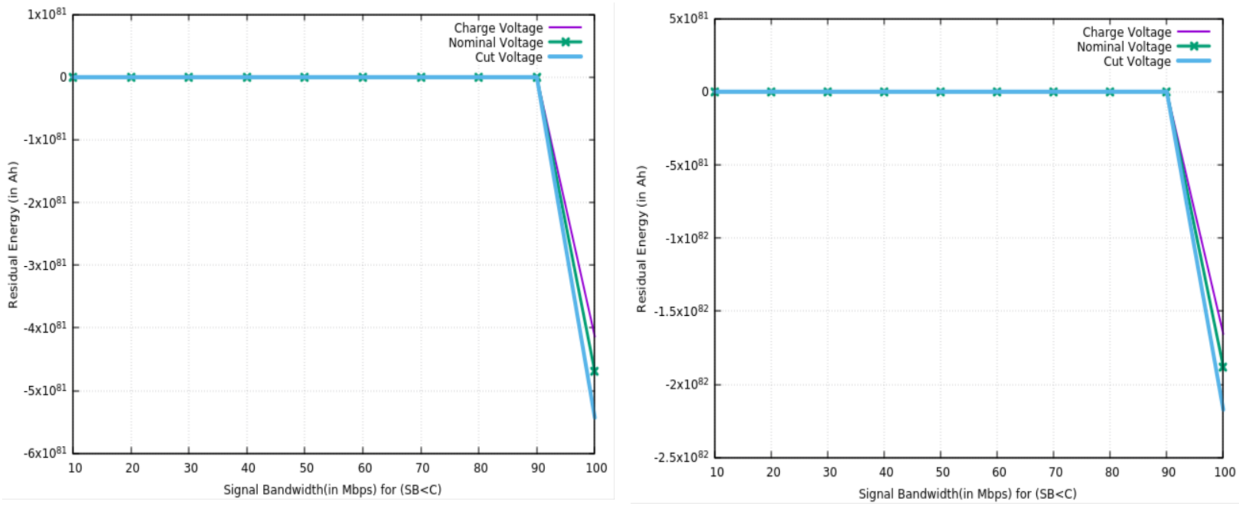

Figure.7. Variation of residual energy with signal bandwidth in noisy channel at SB<C. (a) For Type-I nodes. (b) For Type-II nodes

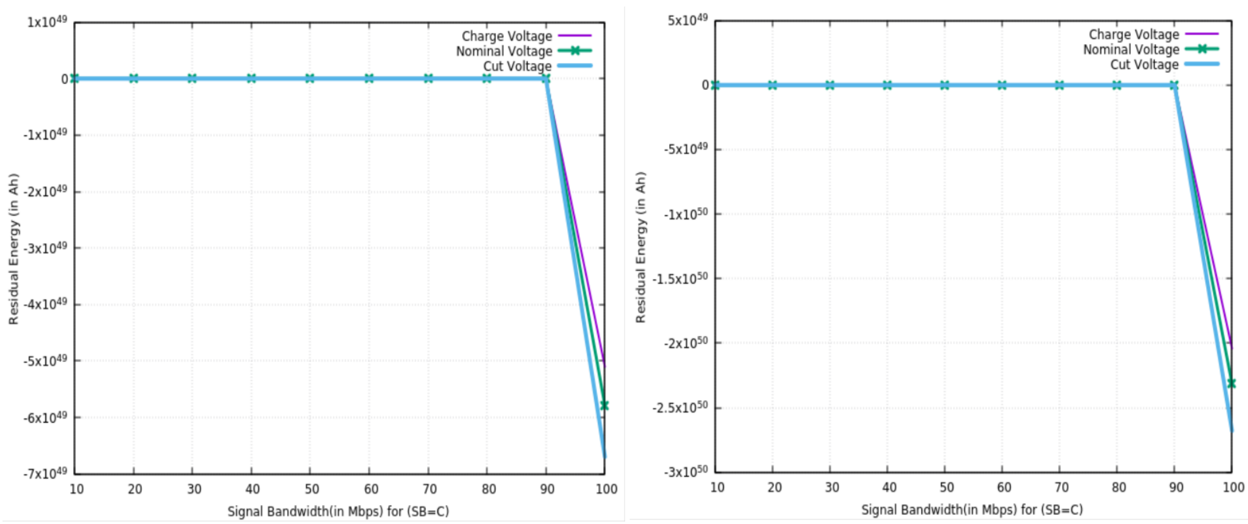

Figure.8. Variation of residual energy with signal bandwidth in noisy channel at SB=C. (a) For Type-I nodes. (b) For Type-II nodes

The variation of cumulative residual energy with signal bandwidth for noisy channel is depicted in Figure 9. The average cumulative residual energy was found to be -2.06937× 10^{80} Ah, -2.34901× 10^{80} Ah and -2.71605 × 10^{80} Ah and -8.27748× 10^{80} Ah, -9.39606× 10^{80} Ah and -1.08642× 10^{81} Ah for Type-I and Type-II nodes respectively at charge, nominal and cut-off voltages respectively.

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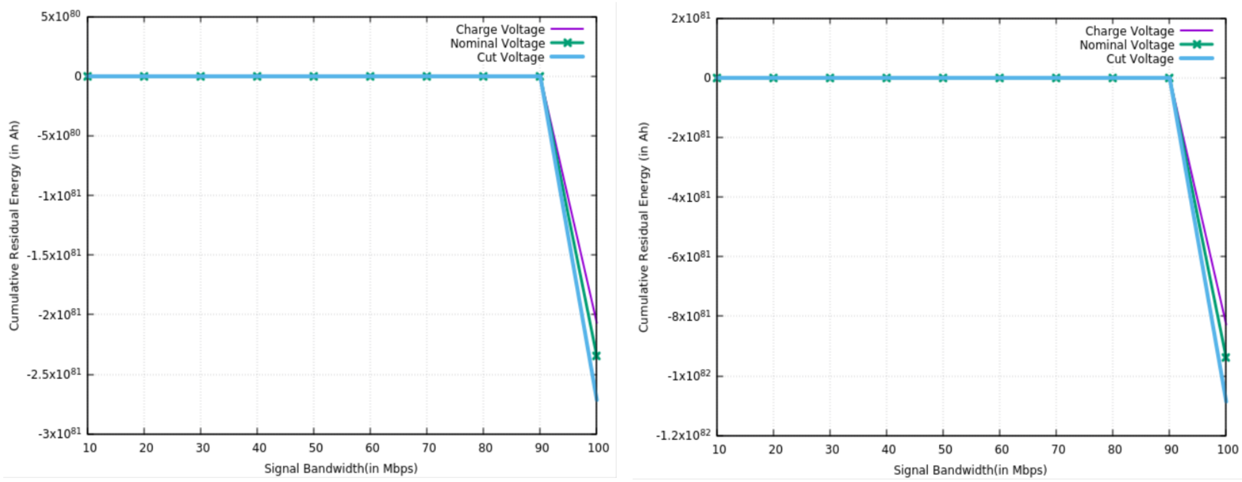

Figure.9. Variation of cumulative residual energy with signal bandwidth in noisy channel.(a) For Type-I nodes. (b) For Type-II nodes

C. Throughput

The throughput of network for this simulation was found to be increasing on increasing the channel capacity of the channel. The graphical representation of variation of throughput with channel capacity for noiseless channel is represented in Figure 10. The average throughput was found to be 51.49499811 Mbps, 50.495 Mbps and 49.495 Mbps and 53.495 Mbps, 51.995 Mbps and 50.495 Mbps for Type-I and Type-II nodes respectively at charge voltage, nominal voltage and cut-off voltage respectively.

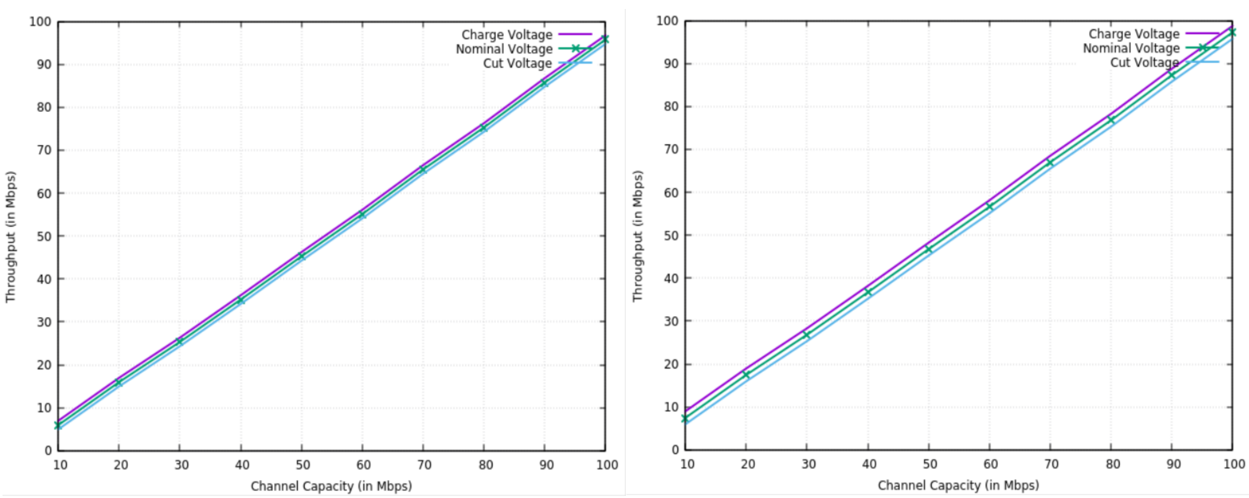

Figure.10. Variation of throughput with channel capacity in noiseless channel.(a) For Type-I nodes. (b) For Type-II nodes

Similarly, for noisy channel, the average throughput was found to be 46.594 Mbps, 41.095 Mbps and 35.595 Mbps and 49.095 Mbps, 43.595 Mbps and 38.095 Mbps for Type-I and Type-II nodes respectively at charge, nominal and cut-off voltages respectively. The graphical representation of throughput variation with channel capacity for noisy channel is represented in Figure 11.

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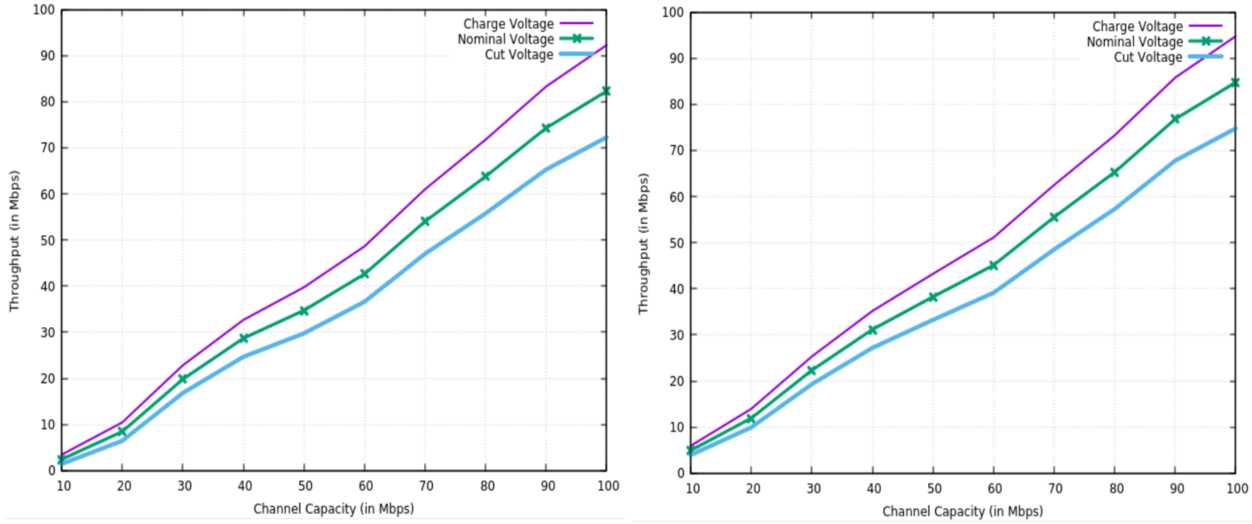

Figure.11. Variation of throughput with channel capacity in noisy channel.(a) For Type-I nodes. (b) For Type-II nodes

D. Packet Delivery Ratio

The Packet Delivery Ratio (PDR) was also found to be increasing on increasing the channel capacity for both noiseless and noisy channels. For noiseless channel, the variation of PDR with channel capacity is represented in Figure 12. For Type-I nodes the average PDR was found to be 0.7812, 0.6812 and 0.5812 and for Type-II nodes, the average PDR was found to be 0.8812, 0.7812 and 0.6812 respectively at charge voltage, nominal voltage and cut-off voltage respectively.

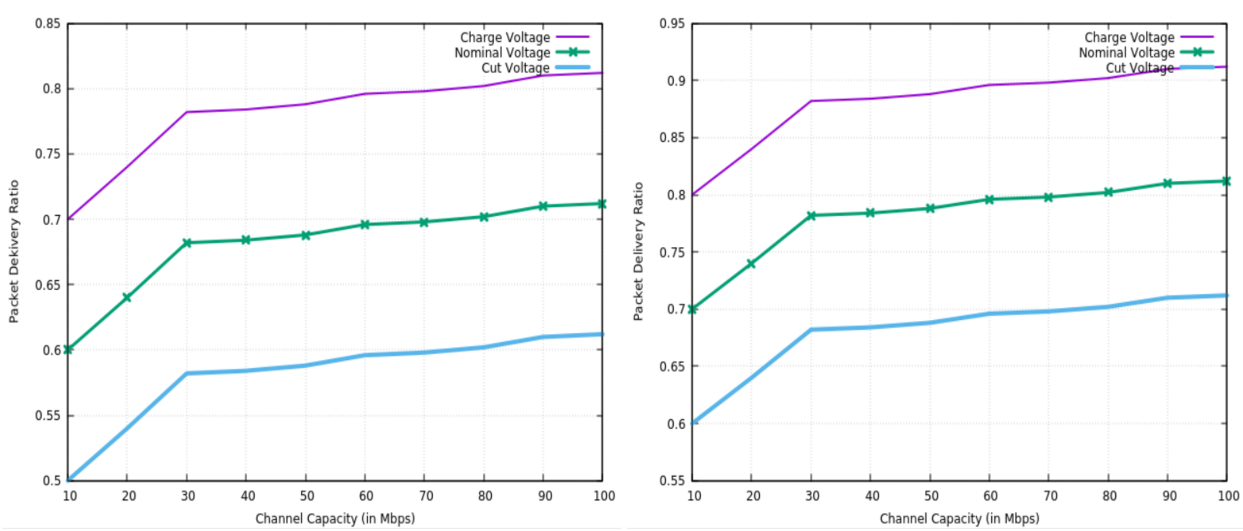

Figure.12. Variation of packet delivery ratio with channel capacity in noiseless channel.(a) For Type-I nodes. (b) For Type-II nodes

Similarly, for noisy channel, the average PDR was found to be 0.7326, 0.6326 and 0.5326 for Type-I nodes and 0.8326, 0.7326 and 0.6326 for Type-II nodes at charge, nominal and cut-off voltages respectively. The graphical representation of variation of PDR with channel capacity for noisy channel is represented in Figure 13.

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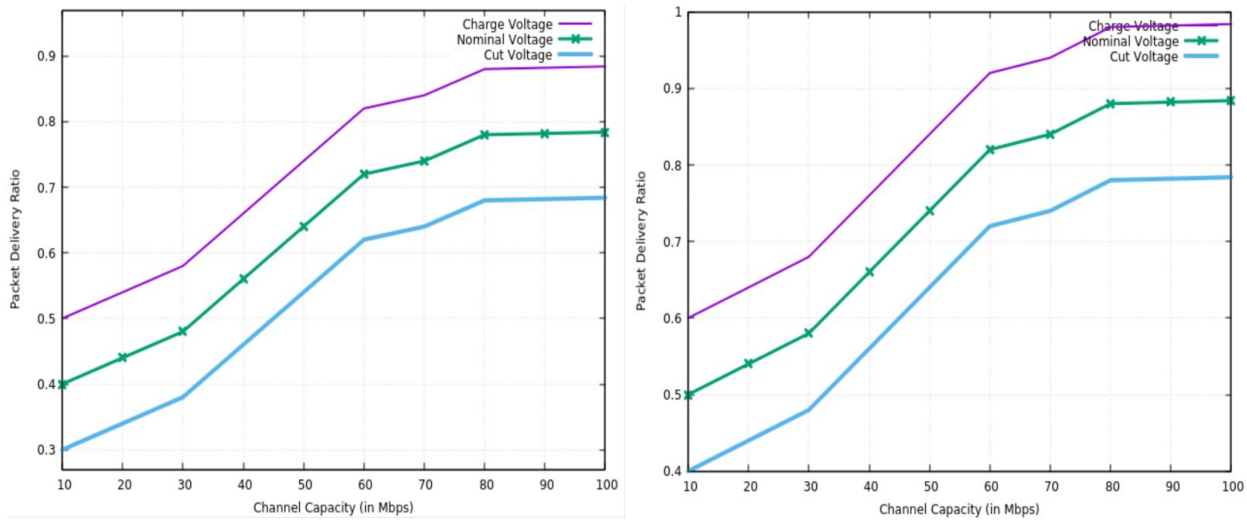

Figure.13. Variation of packet delivery ratio with channel capacity in noisy channel.(a) For Type-I nodes. (b) For Type-II nodes

VI. CONCLUSION

In this study, vertical handover scenario between WiFi and WiMAX network was simulated to study the behavioral pattern of power consumption of wireless nodes with respect to the variations in channel capacity and signal bandwidth. The simulation was performed over Type-I and Type-II wireless nodes at three different voltage levels. The simulation results showed that the power consumption of nodes increased as the channel capacity and signal bandwidth increased for both noiseless and noisy channels. However, the power consumption of nodes was found to be more in noisy channels as compared to the noiseless channels. Similarly, the residual energy was decreased as the channel capacity and signal bandwidth increased for both the channels but was found out to be comparatively more in noiseless channels. Moreover, in noisy channels, the power consumption was found to be less and corresponding residual energy was found to be more when the signal bandwidth was lesser than the channel capacity as compared to when the signal bandwidth was equal to the channel capacity.

For noiseless channel, the average power consumption of Type-I nodes was 1059.181301 Ah and for Type-II nodes was 4236.725204 Ah. Correspondingly, the average residual energy was found to be -1055.681301 Ah for Type-I and -4222.725204 Ah for Type-II nodes respectively. Likewise, for noisy channel, the average power consumption and average residual energy was 2.37814×10^{80} Ah and -2.37814×10^{80} Ah for Type-I and 9.51258×10^{80} Ah and -9.51258×10^{80} Ah for Type-II nodes respectively.

In terms of performance, throughput and PDR of the network increased as the channel capacity and signal bandwidth increased. However, the throughput and PDR was slightly more for noiseless channel as compared to noisy channel. In noiseless channels, the average throughput and average PDR was found to be 50.49499937 Mbps and 0.6812 respectively for Type-I nodes and 51.995 Mbps and 0.7812 respectively for Type-II nodes. Likewise, for noisy channels, the average throughput and average PDR was found to be 41.09499937 Mbps and 0.6326 respectively for Type-I nodes and 43.595 Mbps and 0.7326 respectively for Type-II nodes. Therefore, Type-II nodes outperformed Type-I nodes in terms of network performance.

In relation to voltage levels, for a given bandwidth, the power consumption of both Type-I and Type-II nodes was maximum at cutoff voltage and minimum at charge voltage. Correspondingly, the residual energy was minimum at

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ISSN 1947-5500

cutoff voltage but maximum at charge voltage. Therefore, for optimal energy usage and network performance, the nodes must operate at voltage levels in the range from nominal to charge voltage. This study can provide framework to the researchers towards devising new algorithms for more sustainable green networking.

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