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Research Article

Estimation of Cumulative Power Consumption for New Generation Wireless Networks in Scalable Environment

Vinodini Gupta [1], Padma Bonde [2]
[1] *Shri Shankaracharya Technical Campus, Bhilai, Chhattisgarh, India. Email: gupta.vinu9@gmail.com*
[2] *Shri Shankaracharya Technical Campus, Bhilai, Chhattisgarh, India. Email: bondepadma@gmail.com*

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ABSTRACT

Wireless networking is a crucial component of communication in this era of digitization. The key characteristics that determine a wireless network's performance are smooth connectivity, quicker communication, and increased customer satisfaction. Scalability deals with the erratic workload and new resources that are added to the network. Scalability is crucial for both Quality of Experience (QoE) and Quality of Service (QoS) in such a power-constrained environment because wireless devices are battery-operated. Managing power consumption and network performance simultaneously in scalable networking scenario is quite challenging, especially during handover. This research proposed a methodology to assess the impact of scalability on wireless node power consumption and network performance in order to develop energy-efficient handoff mechanisms. The Type-I and Type-II wireless node sets were used between the WiFI and WiMAX networks in a vertical handover scenario. In the study, two distinct scalability scenarios were taken into account. Three distinct voltage levels—cutoff voltage, nominal voltage, and charge voltage —had been used to examine the consumption of power. Throughput, residual energy, and Packet Delivery Ratio (PDR) were computed to examine the network's performance in a scalable, power-constrained context. Two different scalability scenarios were considered in the study. The power consumption was investigated using three different voltage levels: charge voltage, nominal voltage, and cutoff voltage. The network's performance under scalable, power-constrained conditions was investigated by computing throughput, packet delivery ratio (PDR), and residual energy. The result obtained in the study showed the variation in battery drainage of wireless nodes under the effect of various scalability factors. This study will provide a blueprint for developing novel algorithms which eventually will improvise network performance and strengthen the base of Green Networking.

Keywords: Scalability, Wireless networking, Residual energy, Throughput and Packet Delivery Ratio, Power consumption.

INTRODUCTION

In the present age of digitization, the dependency on wireless networks has been increasing day by day. With increasing demands for faster data rates and seamless connectivity, wireless devices have occupied key responsibility in almost every sphere of humans life. Handover [1] is a scenario of service transition between two networks belonging either to same or different technologies. In telecommunications, QoS and QoE are prime measures to analyze network performance during handover. Amongst multiple factor affecting QoS and QoE standards, Scalability plays important role in meeting the increased user demands in the current digital era.

Scalability basically deals with load balancing and resource management in cost effective and sustainable fashion. Scalable environment in wireless networks can be realized either by intensifying or lessening the number of nodes and the resources associated with individual nodes in the network. Former is known as horizontal scaling and the latter is known as vertical scaling. Vertical scaling can be achieved by variations in bandwidth, power, frequency, time, space etc.

Power consumption is a decisive factor in measuring the performance of wireless networks. Since wireless devices are battery operated, they are power constrained and therefore saving energy levels of wireless devices to ensure better network performance is highly challenging. Analyzing wireless node power consumption due to changes in scalable networking environments is essential since scalable networking, both vertical and horizontal, can significantly impact the energy levels of wireless nodes. This research presents a collective investigation of power utilization in scalable networking scenarios to quantify network performance in the context of sustainable Green Networking (GN). This paper will serve as a framework in devising new power efficient techniques for New Generation Wireless Networks (NGWNs). The paper is further organized as Section 2 to present the significance of scalability in NGWNs, estimation of power consumption due to variations in scalability is exhibited in Section 3. The Section 4 focused on the details of experimental setup used in the simulation. Section 5 analyzed the results obtained during the simulation. Finally, conclusions were drawn in Section 6.

SIGNIFICANCE OF SCALABILITY IN NEW GENERATION WIRELESS NETWORK

Scalability is an significant aspect in shaping the overall performance of wireless networks. QoS and QoE are two important performance standards that are highly affected by scalability. Moreover wireless nodes are battery operated so there is high demand of energy efficient mechanisms [2] to enhance the overall network performance in scalable environment. In present era, fast expanding networks are desirable. In this context, [3] discussed various factors for enhancing scalabilty during deployment of Broadband Wireless Access Networks. Similarly,[4] analysed three different routing protocols over different factors and their impact on scalability of network.[5] discussed the inter dependancy of channel capacity and scalability, the factors affecting network growth and the related problems during deployment of wireless Ad Hoc networks.[6] analysed routing and mobility protocols over cellular nertworks and energy efficient peer to peer networks to enhance the over all scalability of such networks.

Wireless mesh networks are highly desirable in battery operated handheld devices. [7] analyzed the performance and scalability of IEEE 802.11 networks over various factors like topology, throughput and packet drop etc. [8] discussed various scalability and topological issues and mechanisms to overcome these problems in deploying IEEE 802.11s wireless mesh networks.[9] discussed various scaling properties existing in IEEE 802.11 standards and proposed various methods to enhance the scalability of such networks. Similarly, [10] discussed energy-saving schemes to enhance the battery lifetime of nodes in IEEE 802.11s networks. [11] analysed synchronization mechanism of IEEE 802.11 standards using a distributed algorithm to further enhance the scalability of such networks.[12] proposed mathematical models to investigate capacity bottleneck to enhance cumulative capacity and the overall scalability and cumulative throughput capacity.

Performance in scalable environment is quite challenging. In this regard, [13] proposed TCP and UDP based mechanisms to analyze the performance in a scalable Software Defined Wireless Networks (SDWN). Similarly, [14] proposed a routing based framework to enhance scalability of wireless connections in cellular networks.[15] analysed the energy implications and scalability constraints of Network on Chip (NoCs) to improve the performance of wireless on-chip

Communications. To enhance the scalability in NoCs, [16] proposed a NoC with a single broadband channel to provide low latency and ordered delivery.

Hybrid wireless networks increase the capacity of IEEE 802.11 mesh networks to a great extent.[17] analyzed scalability of 3-tier hierarchical hybrid network to enhance the capacity and traffic distribution of mesh networks. Similarly, [18] proposed a 3-tier hierarchical hybrid network to increase Ad Hoc networks' scalability to mesh and sensor networks. IEEE 802.11 wireless networks on a huge scale, interference among nodes degrades the scalability. In this context,

[19] Proposed a protocol to identify factors causing non-scalable performance and proposed the modifications to enhance the scalability. [20] Suggested a multi-tier hierarchical architecture that uses 3D beamforming to improve mesh network scalability and solve the link-sharing issue.

IoT is one of the prominent area that demands high network performance. [21] Proposed cluster based protocol to emphasize the problems with wireless sensor network scalability when implementing them for smart city applications [22] proposed a non-orthogonal multiple access (NOMA) technique for IEEE 802.11 ah standards to reduce access point (AP) conflicts and increase the scalability of IoT networks.

POWER CONSUMPTION DUE TO VARIATIONS IN SCALABILITY OF WIRELESS NETWORKS

Scalable environment in wireless networking can be either horizontal or vertical. Former refers to the scenario where scalability is due to increase or decrease in number of nodes in the network whereas the latter refers to the scalability scenario where the number of resources for each node increases or decreases. The scalable environment in wireless network is depicted in Figure 3.1.

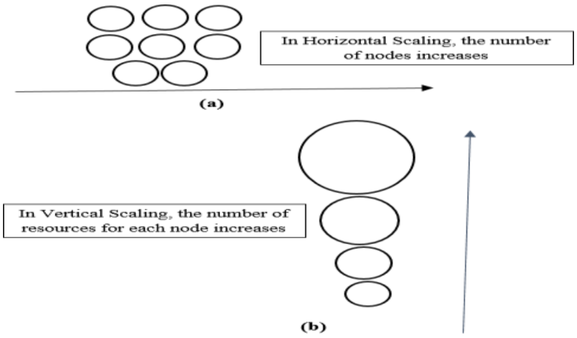

Figure.3.1. Considerations were made a scalable environment integrating diverse scenarios. (a) For Case A. (b) For Case B.

Power consumption in a scalable environment can be either static power or dynamic power. Static power is calculated at no load condition, and dynamic power is the load-dependent power calculated

for actual data transmitted from transmitter to receiver. The steps for analyzing cumulative power consumption in a scalable environment are depicted in Figure 3.2.

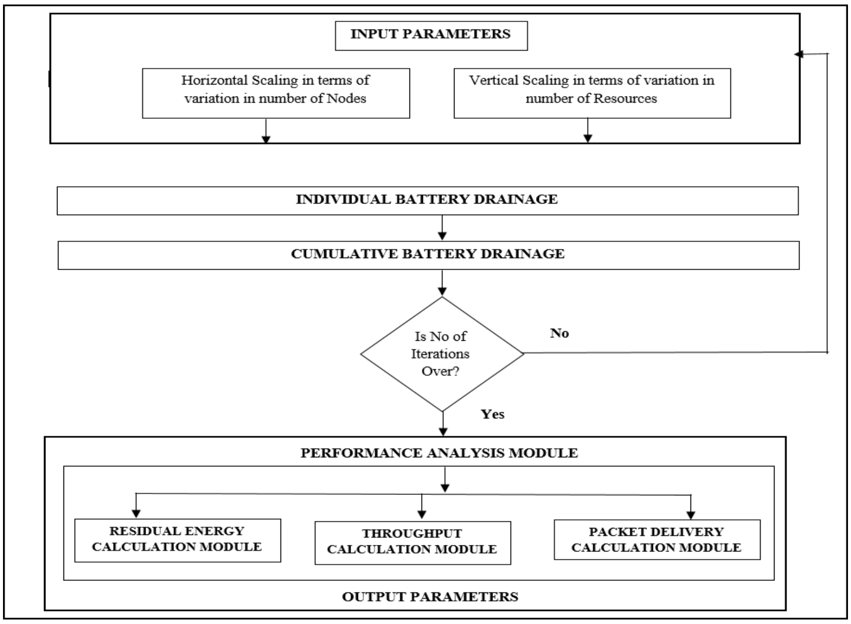

Figure.3.2. Essential Steps for analyzing cumulative power consumption in a scalable environment

Case A: - Horizontal Scalability

The power consumption for horizontal scalability (PHorizontal) in Watts can be calculated as the summation of static power (PHorizontal (static)) in Watts and dynamic power (PHorizontal (dynamic)) in Watts, as given in Equation 1.

$$P_{Horizontal} = P_{Horizontal\ (static)} + P_{Horizontal\ (dynamic)} \quad (1)$$

Dynamic power (PHorizontal (dynamic)) for horizontal scalability for N number of nodes at given data rate (R) (in bps) and Throughput (Th) (in Kbps) is determined using Equation 2 using the transmitted power (P_{tx}) and received power (P_{rx}) in Watts.

$$P_{Horizontal\ (dynamic)} = [(Ptx + P_{rx} * N) / R] * Th \quad (2)$$

Power consumption in horizontal scalability (PHorizontal) is then calibrated to equal power in "Watt-hour (PHorizontal (Wh))" as given in Equation 3 which is further calibrated into equivalent power in Ampere-hour (PHorizontal (Ah)) at a given voltage V (in volts) as given in Equation 4.

$$P_{Horizontal\ (Wh)} = (P_{Horizontal} * T) / 3600 \quad (3)$$

$$P_{Horizontal\ (Ah)} = P_{Horizontal\ (Wh)} / V \quad (4)$$

The average power consumed in horizontal scalability (P (Horizontal (avg))) for n iterations is calculated according to Equation 5. Taking into consideration the standard deviations in energy, the standard power consumption for horizontal scalability (P (Horizontal (std))) can be calculated as given in Equation 6.

$$P_{Horizontal(avg)} = \frac{1}{n} \times \sum_{i=1}^{n} (P_{Horizontal(i)}) \quad (5)$$

$$P_{Horizontal(std)} = \sqrt{\frac{1}{n} \times \sum_{i=1}^{n} (P_{Horizontal(i)} - P_{Horizontal(avg)})^2} \quad (6)$$

Case B: - Vertical Scalability

Similarly, power consumption for vertical scalability (Pvertical) in Watts can be calculated from static power (Pvertical (static)) and dynamic power (Pvertical (dynamic)) in Watts as given in Equation 7

$$P_{vertical} = P_{vertical\ (static)} + P_{vertical\ (dynamic)} \quad (7)$$

If the number of resources for a given node is N, then at a given data rate (R) (in bps) and given Throughput (Th) (in Kbps), the dynamic power (Pvertical [dynamic)) can be calculated according to Equation 8.

$$P_{vertical\ (dynamic)} = [(Ptx * N + P_{rx}) / R] * Th \quad (8)$$

The power consumed (P vertical) is then calibrated to equivalent power in Watt-hour (Pvertical (Wh)) and Ampere-hour (Pvertical (Ah)) at a given voltage V (in volts) according to equation 9 and Equation 10 respectively.

$$P_{vertical\ (Wh)} = (P_{vertical} * T) / 3600 \quad (9)$$

$$P_{vertical\ (Ah)} = P_{vertical\ (Wh)} / V \quad (10)$$

The average power (P (vertical(avg))) and the standard power (P(Vertical(std))) consumed in a vertically scalable environment for n number of iterations can be calculated from Equation 11 and Equation 12 respectively.

$$P_{vertical(avg)} = \frac{1}{n} \times \sum_{i=1}^{n} (P_{Vertical(i)}) \quad (11)$$

$$P_{Vertical(std)} = \sqrt{\frac{1}{n} \times \sum_{i=1}^{n} (P_{Vertical(i)} - P_{Vertical(avg)})^2} \quad (12)$$

EXPERIMENTAL SETUP

To inspect the influence over scalability, a handoff scenario between "Wi-Fi (IEEE 802.11n standards)" and "WiMAX (IEEE 802.16 standards)" technology was simulated using "Network Simulator software (NS-2)". Figure 4.1 depicts the simulated situation, and Table 4.1 below lists further simulation details.

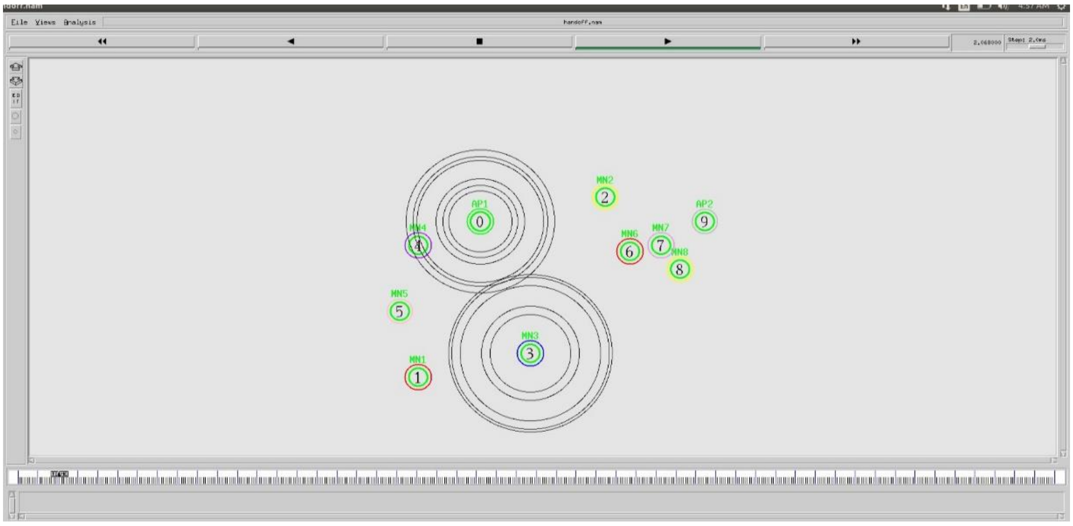

Figure.4.1. Simulation Scenario

Table 4.1: Simulation Parameters

Configuration	Parametric Values
Number of Nodes	10 – 100
Simulation Area	600 * 600
Number of Resources	10 – 100
Access Points	2
Traffic Type	CBR
Propagation Model	Two Ray Ground
Voltage Levels	4.2V, 3.7V and 3.2V
Packet Size	1023 bytes
Bandwidth	1 Mbps

The “Type-I” nodes consist of a 3500 mAh Li-ion battery with a 3.7 volt capacity, whereas the “Type-II” nodes are composed of four cells with a 14.8 volt voltage and a 3500 mAh capacity. To determine how much power each node in a scalable system used, the simulation examples were created for two distinct scaling scenarios. Additionally, three distinct voltage levels were used for the power consumption analysis: 4.2 volts, 3.7 volts, and 3.2 volts, respectively, were the “nominal voltage”, “charge voltage”, and “cut-off voltage”. Other factors influencing nodes' power usage are regarded as insignificant under experimental conditions. By altering the number of nodes, the power consumption of nodes in a scalable system was determined. Ranging from 10 to 100 nodes and by varying the number of resources for each node ranging from 10 to 100 resources under Scenario-I and Scenario-II respectively.

RESULT ANALYSIS AND DISCUSSION

Result Analysis

For “Type-I” nodes, the power consumption was 168.0123 Ah, 168.0139 Ah, and 168.0161 Ah at “charge voltage”, “nominal voltage”, and cut off voltage; for “Type-II” nodes, it was 2688.049 Ah, 2688.055 Ah, and 2688.064 Ah. In scenario I, scalability was achieved by varying the number of nodes. According to Figure 5.1 and Figure 5.2, the residual energy under the same conditions was determined to be -164.512 Ah and -2674.049 Ah at “charge voltage”, -164.513 Ah and -2674.055 Ah at “nominal voltage”, and -164.516 Ah and -2674.064 Ah at “cut-off voltage” for “Type-I” and “Type-II” nodes, respectively. Under this situation, “Type-I” nodes' average power consumption and residual energy were 168.014 Ah and -164.514 Ah, respectively, while “Type-II” nodes' were 2688.056 Ah and -2674.056 Ah.

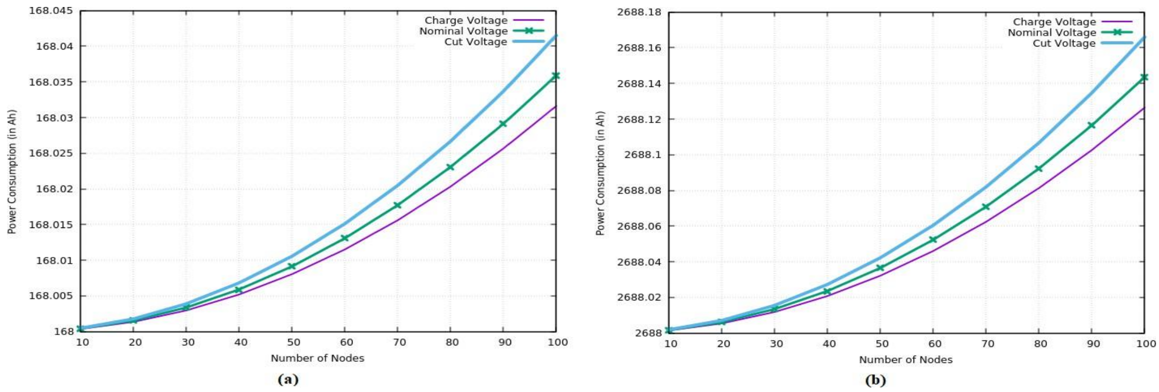

Figure 5.1. Variation of power consumption in scalable environment by variations in a number of nodes (a) For "Type-I" nodes. (b) For "Type-II" nodes.

Figure 5.4 shows the fluctuation of residual energy for "Type-I" and "Type-II" nodes beneath Scenario-II. "Type-I" node residual energy was -164.521 Ah, -164.524 Ah, and -164.528 Ah at "charge voltage", "nominal voltage", and "cut-off voltage". And for "Type-II" nodes was -2674.086 Ah, -2674.098 Ah and -2674.113 Ah respectively. The average residual energy under this scenario was found to be -164.524927 Ah for "Type-I" nodes and -2674.099 Ah for "Type-II" nodes.

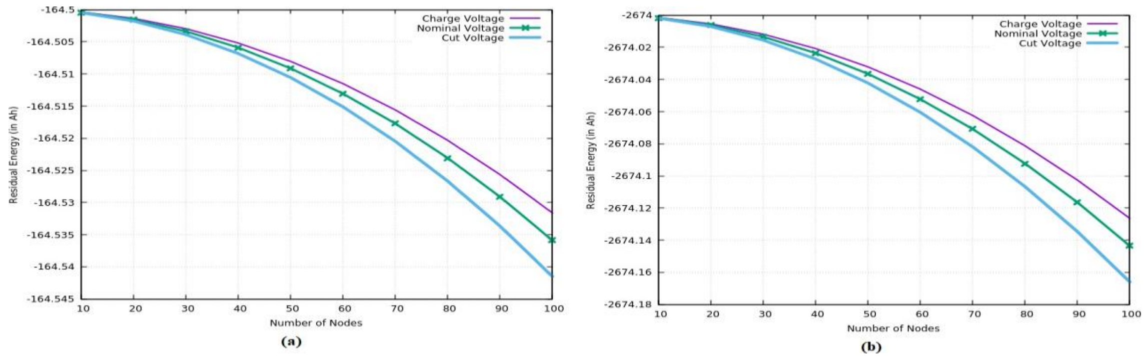

Figure 5.2. Variation of residual energy in scalable environment by variations in number of nodes (a) For "Type-I" nodes. (b) For "Type-II" nodes.

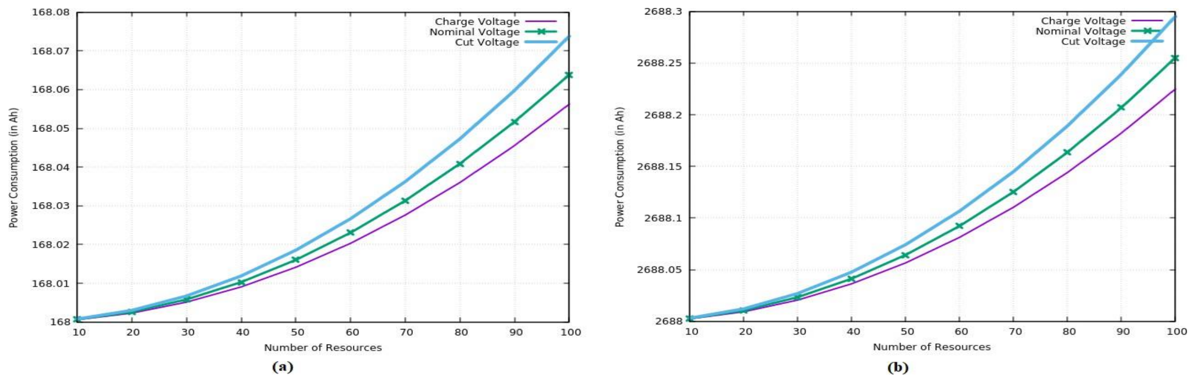

Figure 5.3. Variation of power consumption in scalable environment by variations in number of resources of particular node (a) For "Type-I" nodes. (b) For "Type-II" nodes.

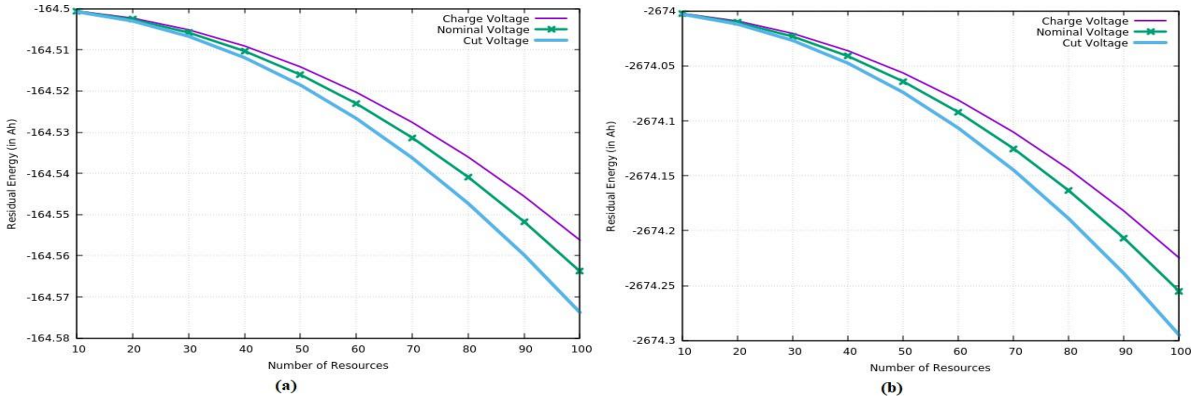

Figure 5.4. Variation of residual energy in scalable environment by variations in a number of resources of particular node (a) For Type-I nodes. (b) For Type-II nodes.

Figures 5.5 and 5.6 show how cumulative power consumption and residual energy vary in a scalable system when the number of nodes and resources associated with each node changes. At charge voltage, Type-Type-II nodes and I consumed 336.033 and 5376.135 ah, at nominal voltage, 336.038 and 5376.154 ah, and at cut-off voltage, 336.044 and 5376.178 ah, respectively. The residual energy for Type-I and Type-II nodes and I was -329.033 Ah and -5348.135 Ah at charge voltage, -329.038 Ah and -5348.154 Ah at nominal voltage, and -329.044 Ah and -5348.178 Ah at cut-off voltage. Type-II nodes and I had average cumulative residual energy of -329.039 Ah and -5348.156 Ah and average cumulative power consumption of 336.039 Ah and 5376.156 Ah, respectively.

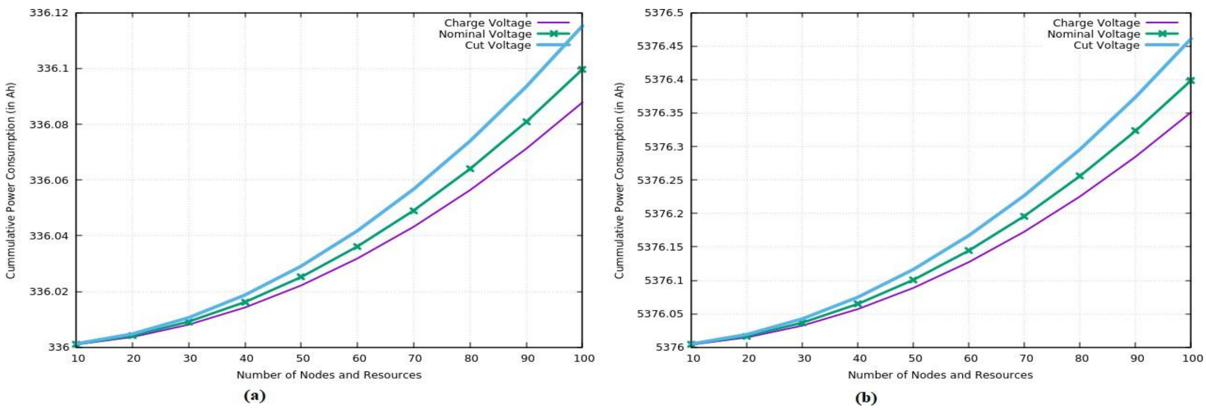

Figure 5.5. Variation of cumulative power consumption in scalable environment by variations in a number of nodes and resources of particular node (a) For Type-I nodes. (b) For Type-II nodes.

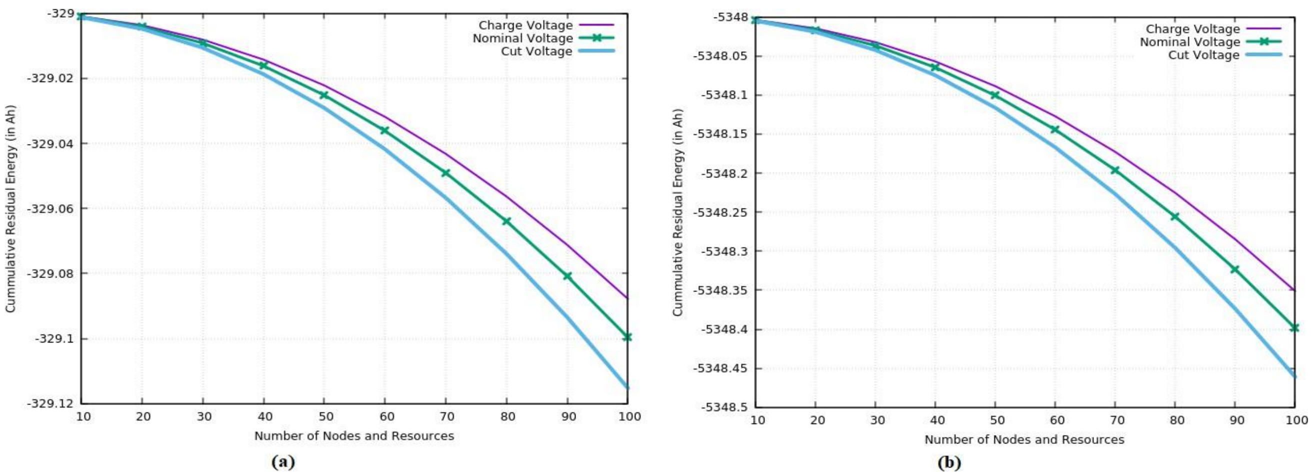

Figure 5.6. Variation of cumulative residual energy in scalable environment by variations in number of nodes and resources of particular node (a) For Type-I nodes. (b) For Type-II nodes.

The throughput variance for Type-I and Type-II nodes under the two scalability scenarios is shown in Figure 5.7 and Figure 5.8, respectively. The throughput for Type-I nodes was 115.689 Kbps, 101.917 Kbps, and 88.144 Kbps under Scenario-I and 115.709 Kbps, 101.937 Kbps, and 88.164 Kbps under Scenario-II at charge voltage, nominal voltage, and cut-off voltage. Regarding Type-I nodes at nominal, cut-off, and charge voltages, the cumulative throughput of Scenarios I and II was determined to be 115.699 Kbps, 101.927 Kbps, and 88.154 Kbps, respectively. Under Scenario I, the average throughput was 101.917 Kbps, and under Scenario II, it was 101.937 Kbps. The two scenarios' respective average total throughputs were 101.957 Kbps.

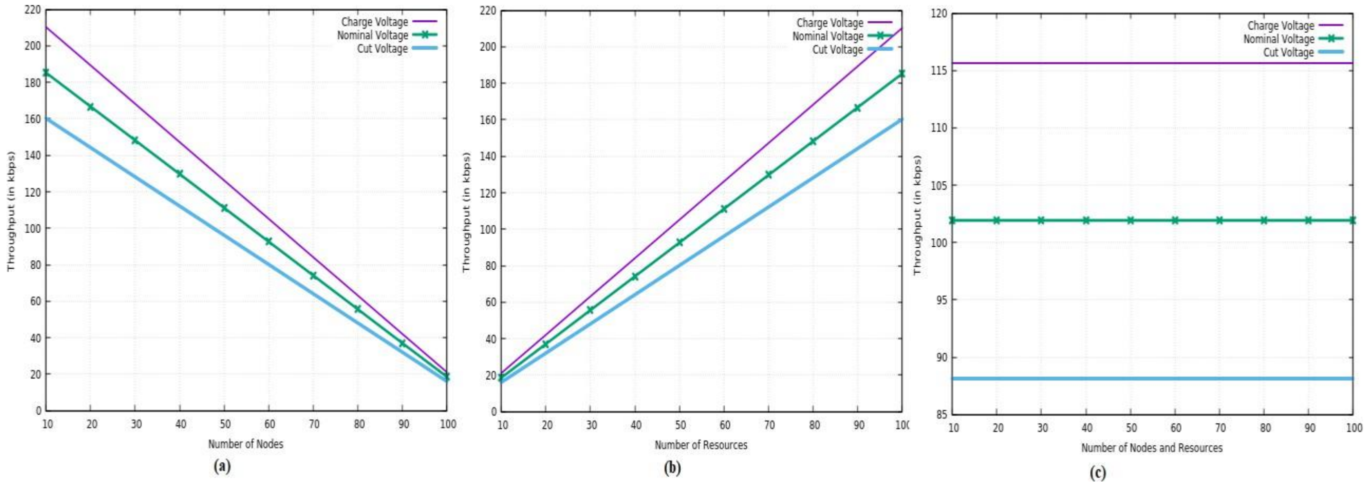

Figure 5.7. Variation of throughput in scalable environment for Type-I Nodes (a) For Scenario-I (b) For Scenario-II. (c) Cumulative throughput of Scenario-Scenario-II & I

For Type-II nodes, the throughput was 462.759 Kbps, 407.669 Kbps, and 352.578 Kbps under Scenario-I and 462.779 Kbps, 407.689 Kbps, and 352.598 Kbps under Situation II at the nominal voltage, charge voltage, and cut-off voltage, in that order. For Type-I nodes at charge voltage, nominal voltage, and cut-off voltage, the cumulative throughput of Scenarios I and II was determined to be 462.769 Kbps, 407.679 Kbps, and 352.588 Kbps, respectively. The typical throughput was

Determined to be 407.679 Kbps in Scenario II and 407.669 Kbps in Scenario I. The average cumulative throughput of both the scenarios was 407.689 Kbps.

The PDR for Type-I nodes was correspondingly 0.115, 0.101, and 0.088 under Scenario-I and 0.135, 0.21, and 0.108 under Scenario-II at charge voltage, nominal voltage, and cut-off voltage. The cumulative PDR of Scenarios I and II for Type-I nodes at charge voltage, nominal voltage, and cut-off voltage were found to be 0.125, 0.111, and 0.098, respectively. Under Scenario I, the average PDR was 0.101, whereas under Scenario II, it was 0.103. Between the two cases, the average cumulative PDR was 0.102. In Figure 5.9 and Figure 5.10, respectively, the PDR variation for Type-I and Type-II nodes under the two scalability scenarios is graphically displayed.

In Scenarios II, the PDR for Type-II nodes at charge voltage, nominal voltage, and cut-off voltage and I were 0.462, 0.407, and 0.352, respectively, and 0.482, 0.427, and 0.372, respectively. For Type-I nodes at charge voltage, nominal voltage, and cut-off voltage, the cumulative PDR of Scenarios I and II was determined to be 0.472, 0.417, and 0.362, respectively. In Scenario I, the average PDR was 0.407, and in Scenario II, it was 0.409. For the two cases, the average total PDR was 0.408. For Type-I nodes at charge voltage, nominal voltage, and cut-off voltage, the cumulative PDR of Scenarios I and II was determined to be 0.472, 0.417, and 0.362, respectively. The average PDR was 0.407 in Scenario I and 0.409 under Scenario II. The average total PDR for the two cases was 0.408.

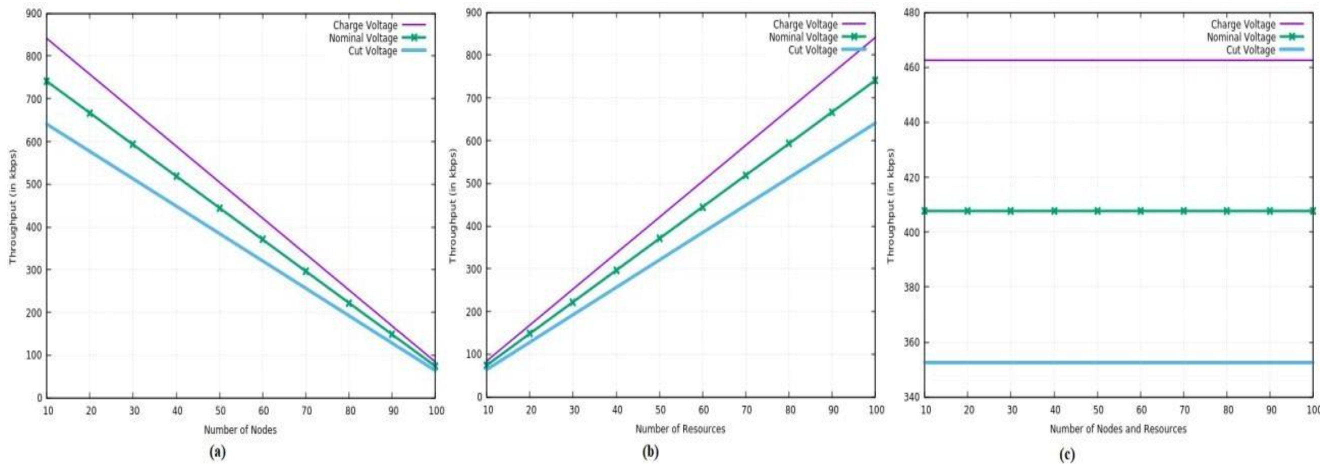

Figure 5.8. Variation of throughput in scalable environment for Type-II Nodes (a) For Scenario- I (b) For Scenario-II. (c) Cumulative of Scenario-I & Scenario-II

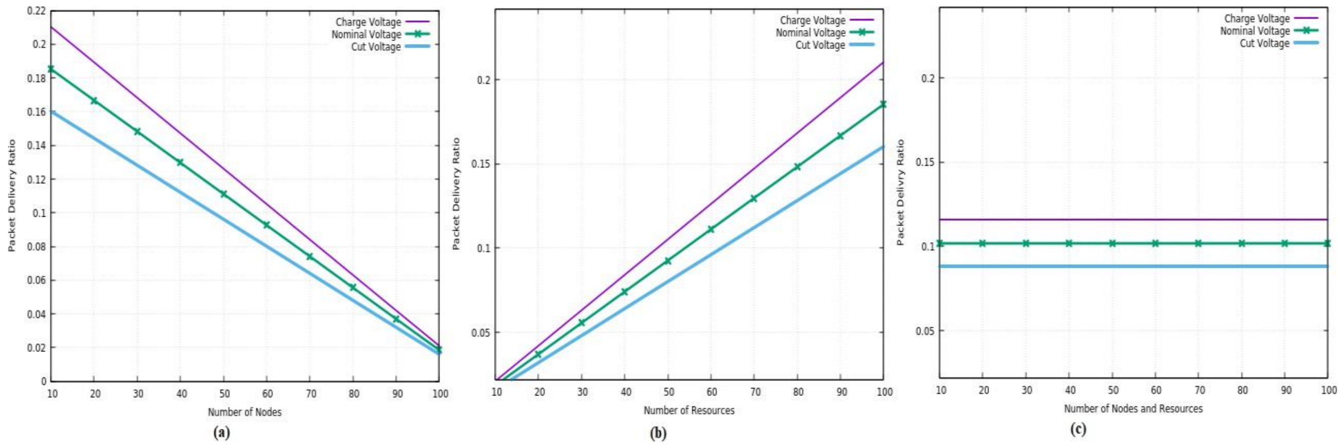

Figure 5.9. Variation of packet delivery ratio in scalable environment for Type-I Nodes (a) For Scenario-I (b) For Scenario-II. (c) Cumulative of Scenario-I & Scenario-II

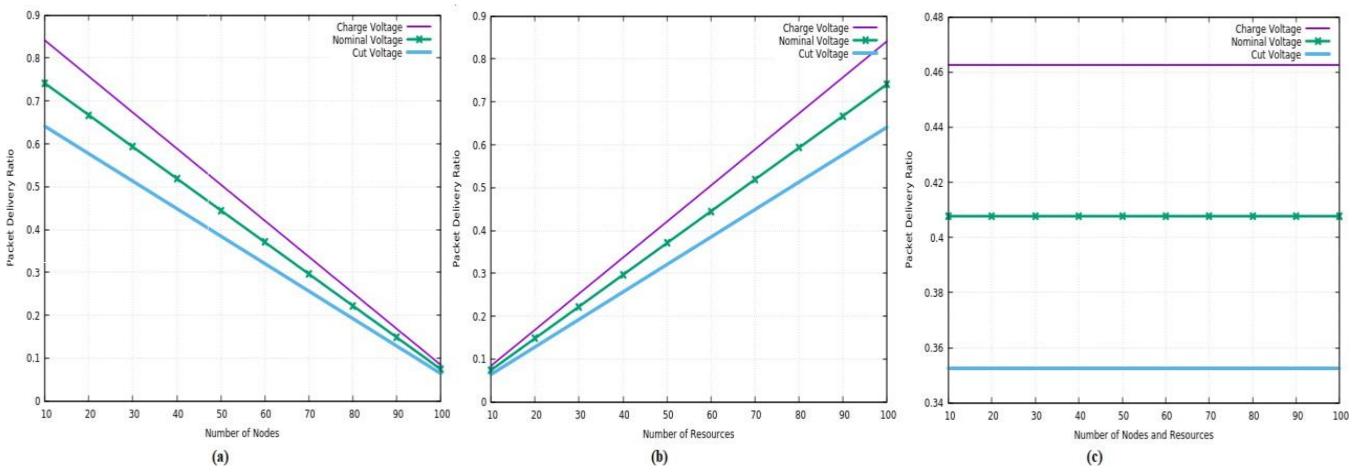

Figure 5.10. Variation of packet delivery ratio in scalable environment for Type-II Nodes (a) For Scenario-I (b) For Scenario-II. (c) Cumulative of Scenario-I & Scenario-II

DISCUSSIONS

- For both Type-I and Type-II nodes in Scenarios I and II, power consumption rose while residual energy fell with each iteration. Compared to Type-II nodes, Type-I nodes consumed more electricity. For both Type-Type-II nodes, and I the power consumption was relatively lower at the normal voltage, but it was highest at the charging voltage and lowest at the cut-off voltage. But compared to Scenario I, Scenario II used a lot more power. With each repetition, the cumulative power consumption increased and the cumulative residual energy decreased for both Type-I and Type-II nodes. All things considered, Type-I nodes used less power than Type-II nodes. Charge voltage in relation to the voltage that is stated.

- The cumulative power consumption was comparatively lower at the nominal voltage for both Type-I and Type-II nodes, but it was highest at the charging voltage and lowest at the cut-off voltage. In Scenario I, the throughput decreased for both Type-I and Type-II nodes with each iteration. However, the throughput of Type-II nodes was comparatively larger than that of Type-I nodes. Similarly, in comparison to the nominal voltage, the throughput was highest at the charge voltage and lowest at the cut-off voltage.
- In Scenario II, both Type-1 Type-II nodes and I saw an increase in throughput with each iteration. It was discovered that the cumulative throughput of Scenarios I and II remained consistent during each repetition. However, the throughput of Type-II nodes was comparatively larger than that of Type-I nodes. Similarly, in comparison to the nominal voltage, the throughput was highest at the “charge voltage” and lowest at the cut-off voltage.
- For both Type-I and Type-II nodes, the PDR dropped with each iteration in Scenario I. On the other hand, Type-I nodes had a lower PDR than Type-II nodes. In a similar vein, the PDR was lowest at the cut-off voltage and higher at the charge voltage relative to the nominal voltage.
- Each recapitulation, for both Type-I and Type-II nodes in Scenario-II, the PDR rose. It was discovered that the cumulative throughput of Scenarios I and II remained consistent during each repetition. Nonetheless, Type-I nodes had a lower PDR than Type-II nodes. In a similar vein, the PDR was lowest at the cut-off voltage and higher at the charge voltage relative to the nominal voltage.

CONCLUSION

This study used a comparative analysis to investigate how scalability variation affects wireless nodes' power consumption. Power consumption was calculated for Type-I and Type-II nodes at three different voltage levels: charge voltage, nominal voltage, and “cut-off voltage”. Scalability variation was assessed under two scenarios in which the number of nodes and resources of each node increased to achieve scalability. According to the findings of the simulation, nodes' power consumption rose as their numbers and individual resources grew. However, it was discovered that when a node's resources grew, the power consumption increased more than when the number of nodes increased. The collective power consumption to examine the shared impact of both scaling scenarios—that is, growing node numbers and individual node resources—was shown to be rising with each iteration under the specified set of experimental variables.

The findings correspondingly demonstrated that as the voltage levels shifted from charge voltage to nominal voltage to cutoff voltage, power consumption rose. It was discovered that Type-I and Type-II nodes consumed the most power at cutoff voltage, a little more at normal voltage, and the least at charge voltage. Nonetheless, it was discovered that Type-I nodes used a relatively smaller amount of electricity than Type-II nodes. In Scenario-I, where the number of nodes increased in each iteration for both Type-I and Type-II nodes, it was also noted that throughput and PDR fell as power consumption increased. In Scenario-II, on the other hand, where the amount of resources linked to a specific node increased in each iteration for both Type-I and Type-II nodes, throughput and PDR rose while power consumption increased.

Nevertheless, it was discovered that when the number of nodes and resources connected to each node increased, the cumulative throughput and PDR used to examine the overall impact of both scaling scenarios remained consistent. It was discovered that the throughput and PDR were lowest at cut-off voltage, highest at charge voltage, and relatively lowest at nominal voltage. According to simulation studies, Type-II nodes performed better than Type-I nodes in terms of PDR and throughput. Numerous studies and investigations have been carried out to examine how scalability affects wireless networks' overall performance and power consumption. This study, however, examined the combined impact of several scaling parameters on wireless network performance and power consumption. As a result, this study can offer a solid framework for creating innovative energy-efficient NGWNs that support sustainable green networking.

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