Network Protocols and Algorithms
ISSN 1943-3581
2013, Vol. 5, No. 1

Comparing Communication Protocols within an Enterprise Network for Carbon Footprint Reduction

Sami J. Habib and Paulvanna N. Marimuthu

Kuwait University

Computer Engineering Department

P. O. Box 5969 Safat 13060 Kuwait

sami.habib@ku.edu.kw

Received: March 2, 2013 Accepted: March 15, 2013 Published: March 31, 2013

DOI: 10.5296/npa.v5i1.3342 URL: http://dx.doi.org/10.5296/ npa.v5i1.3342

Abstract

The enormous growth in enterprise networks such as cloud computing and social networking increase the network traffic, thereby contributing considerably to the total carbon emission within the network. In this paper, we present a comparison study between transport-layer communication protocols relative to carbon footprint within enterprise network. The comparative study focuses on three factors: the transport layer communication protocols (TCP and UDP), the QoS offered by the transmission line, and the data encoding schemes in the physical layer. The QoS of the transmission line and the number of transmissions contribute significantly to the total carbon footprint generated by the enterprise network. The carbon footprint is estimated from the power spectrum of the transmitted packets through Manchester coding. The carbon reduction at the backbone is of prime importance, since the enterprise is often susceptible to heavy transactions at the backbone. We have formulated the carbon footprint reduction within the enterprise as an optimization problem, wherein the given single enterprise is synthesized into suitable clusters by localizing the heavily communicating nodes together. The simulation results demonstrate that a typical single enterprise comprising of 100 nodes with 4 GB generated backbone traffic when both the UDP and TCP utilize high capacity link, produce low and nearly equal volumes of carbon. However, the difference becomes significantly high with the link offering poor QoS, in which, UDP based transmissions produce 14% less carbon than TCP based transmissions. The optimization within the molecular assembly algorithm manages to produce 64.5% reduced annual carbon emission than the initial network.

Keywords: carbon footprint, data encoding, molecular assembly, optimization, TCP and UDP.

1. Introduction

The communication protocols offering end-to-end services within an enterprise network (EN) mainly utilize the message format defined by transmission control protocol (TCP) or user datagram protocol (UDP) [1]. TCP offers connection oriented services with data read as byte stream, whereas UDP is connectionless with data communicated as datagram. The two protocols are differed in QoS properties, such as reliability, throughput and power consumption. Data transmissions under various transmission frame formats differ in their payload size, which carries the actual data to be transmitted through the physical layer. The volume of data produced at the backbone of an enterprise greater than the payload size needs to be segmented to fit into the transmission frame. The length of the payload field is influenced by the choice of communication protocols and the quality of the transmission link. The variation in the header field of the transport layer protocols also affects the total volume of data to be transmitted under a specified transmission frame. In addition, the quality of service guarantees a certain level of performance; high QoS provides maximum utilization of the transmission line allowing the segmented packet to carry maximum transmission load of the selected protocol, thereby reduces the number of transmissions and the carbon emission.

The segmented data packets from network layer are coded into raw bits through the data encoding techniques during the transmission through physical layer. The data encoding techniques include simplest polar encoding technique to slightly complex Manchester encoding. Manchester encoding is widely used in data transmission, as it facilitates low-cost radio-frequency (RF) transmission of digital data [2]. The data encoding technique computes the average power consumed in transmitting the specified volume of data by integrating the corresponding power density spectrum of the transmitted data over a specified frequency interval.

In an enterprise, the overall energy consumed during the transmission of a data packet can be estimated by integrating the energy usage from transport layer to physical layer, which depends on the choice of transmission protocols, the QoS of transmission link and the data encoding mechanisms employed in raw data transmission. The present issues in greenhouse gas (GHG) emissions demand the enterprise networks to practice some strategies to cut down their energy usage and to produce less carbon. In enterprise networks, the backbone network is often susceptible to heavy traffic and it is inevitable to mitigate carbon at the backbone to offer green communications. One of the possibilities to achieve green communication within an EN is through efficient management of resources using optimization algorithms to reduce the external data traffic. The optimization algorithms normally employ heuristic techniques to reduce the amount of data generated at the backbone. Conversely, we have selected molecular assembly (MA), a bio-inspired approach, which exploits the basic principle behind the assembly of molecules in nature. MA utilizes the local interactions between the molecules to organize a given disorganized system into a structured assembly [3]. In enterprise network environment, the molecular assembly is redefined with distance, incoming traffic and outgoing traffic as the forces of attractions for optimizing the backbone traffic.

In this paper, we present a comparative study between the transport layer communication protocols (TCP and UDP), based on the carbon footprint produced by the data traffic at the backbone of an enterprise network. The comparative study integrates the carbon footprint estimated in transmitting the backbone data from transport layer to physical layer and it considers the overhead introduced by the communication protocols and the QoS of the transmission line on the payload size of a transmission frame, which influences the number of packets to be transmitted for the specified traffic volumes. The Manchester data encoding scheme estimates the power density spectrum corresponds to each transmission and integrates the spectrum to obtain the equivalent energy consumed in each transmission. Subsequently, it utilizes energy-carbon conversion factor for estimating the carbon footprint. We formulate the carbon footprint reduction as an optimization problem, whereby MA is exploited to generate suitable clusters to reduce carbon emission at the backbone. The simulation of a typical single enterprise with 100 nodes with heavy backbone traffic of around 4 GB and transmitting data using high quality transmission link shows only marginal variation (1%) in carbon emission between UDP and TCP protocols. However, UDP performs better with 14% reduced carbon footprint than TCP when the transmission line quality is poor. The simulation experiment also analyzes various scenarios demonstrating multiple traffic patterns and varying QoS, whereby it is observed that UDP based transmissions within MA yields 64.5% reduced carbon emission than the initial network.

The paper is organized into 6 sections. Section 1 details the concept behind the proposed comparative study. Section 2 examines the related work, whereas Section 3 describes the problem formulation, molecular assembly and carbon footprint computation. Section 4 provides the algorithm to estimate the carbon footprint and Section 5 details the experimental results. Section 6 concludes the paper.

2. Related Work

We have surveyed various research works for comparing the communication protocols against their performance while operating under various platforms. With respect to our knowledge, most of the publications are limited to the study of performance measures of the communication protocols within transport layer and none of them attempted to integrate the carbon footprint from transport layer to physical layer. Giannoulis et al. [4] studied the QoS and power management of the transport layer of the protocol stack, wherein they discussed the performance of TCP and UDP. Garcia et al. [5] analyzed the Ethernet frame payload size on IPv4 and IPv6 traffic, taking into consideration about TCP and UDP. Zhang et al. [6] analyzed the throughput and reliability of communication protocols in pervasive computing environment. Rind et al. [7] discussed the performance of TCP and UDP protocols over wired and wireless local area networks and they measured the throughput to evaluate the performance.

The recent growths in information and communication sector add more carbon footprint to the environment, thereby demanding the development of various strategies to reduce GHG emissions. Koutitas [8] investigated the telecommunication network and the author proposed genetic algorithm based optimization technique to design the network with reduced carbon emissions. Despins et al. [9] discussed the necessity in providing green communications in information and communication technology (ICT) industries and he briefed the ongoing efforts in standardizing the methodologies to reduce GHG emissions. In another work, Peng and Wang [10] proposed an ICT solutions calculation model for CO_2 emissions and they introduced an emission reduction index based on the model.

The self-organizing and the self-repairing behavior of molecules are exploited in the design of computer networks [11]. The authors described the advantages of autonomic assembly of molecules and their application in computing. Habib and Marimuthu [12] presented a molecular assembly based network design tool to integrate the nodes in a given network into various clusters utilizing distance and traffic as forces of attractions. The authors claimed that the optimized and clustered network generated using the tool was able to reduce the backbone traffic. The authors also proposed a capacity planning scheme based on molecular assembly (MA) to manage CO_2 emission at the backbone with distance as the force of attraction to comply with the standards of fiber-optic and Wi-Fi connectivity [13]. In an approach to estimate the carbon footprint the authors claimed that redesigning the existing network topology within Simulated Annealing led to reduction in carbon emission [14][15].

In this paper, we have employed molecular assembly to generate clusters of associated nodes with outgoing traffic chosen as the force of attraction with an objective function to reduce carbon footprint. The data transmission is limited by QoS of the transmission line and the de facto size of the packets corresponding to the transport layer protocols TCP and UDP. We have executed a number of experiments to explore the feasibility in reducing the CO_2 emission at the backbone of EN.

3. Problem Formulation

The carbon footprint of a backbone network within an enterprise is estimated by integrating the carbon emissions during the data transmission from transport layer to physical layer.

3.1 Ethernet Transmission Frame

We have investigated the carbon footprint emission at the backbone of an enterprise network by analyzing the transmission of the generated data using TCP and UDP protocols. The choice of protocol alters the payload size of the packet to be transmitted, thereby affects the number of transmissions. Ethernet frame discussed in [16] is selected as a reference, since the local area networks are mostly Ethernet based and they add more traffic in an enterprise. The maximum size of the transmitted packet using Ethernet frame is chosen as 1518 bytes. The difference between TCP and UDP is mainly on the header size, which is 20 bytes for TCP and 8 bytes for UDP as illustrated in Fig. 1. The generated traffic at the backbone is spilt into varying number of TCP segments and UDP datagram before they are transmitted through the physical layer.

3.2 QoS of the Transmission Line

The efficiency of the transmission line further restricts the size of the packet/datagram to be transmitted, which is varied from 20% (poor) to 100% (ideal) in the simulations. The total number of transmissions required for transmitting the generated data at the backbone depends on the size of the packet, which is given by Equation (1). Hereby, the data to be transmitted is limited by the QoS of the transmission line. High quality transmission line increases the length of the payload to be transmitted, thereby reduces the number of transmissions required to complete the data transfer. Consequently, the carbon footprint associated with the number of transmission decreases.

$$Total\ number\ of\ transmission = \frac{data\ to\ be\ transmitted\ (bits)}{Maximum\ size\ of\ a\ packet\ or\ datagram\ (bits)} \quad (1)$$

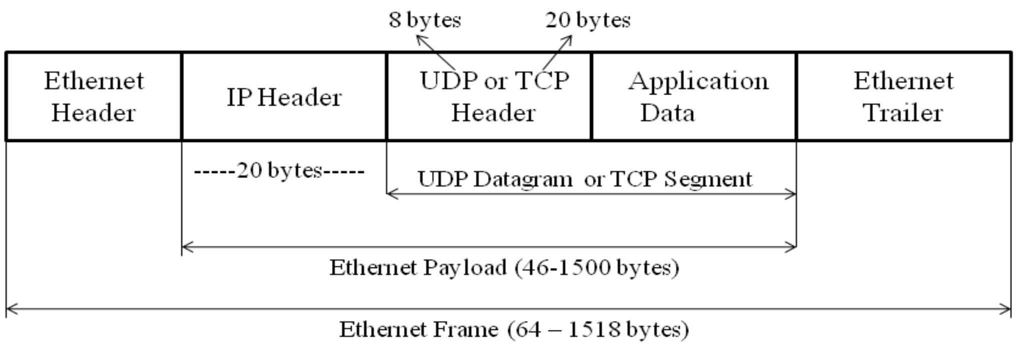

Figure 1. Ethernet frame format.

3.3 Molecular Forces of Attraction

The initial network is a single clustered network comprised of a set of nodes, $N = \{n_1, n_2, n_3, \ldots, n_M\}$ distributed in a given 2-dimensional area A, where M represents the total number of nodes present. The outgoing traffic from each node is considered as the force of attraction to discover the node assembly, which is defined by the set of Equations (2-4). Equation (2) indicates that a cluster G_j starts empty of nodes and Equation (3) examines all distinct pairwise nodes within EN to determines whether an outgoing traffic force (OTF) exists between any two nodes n_i and n_j, where tr_{n_i,n_j} describes the traffic flow between n_i and n_j.

The molecular assembly produces a set of k clusters $\{G_1, G_2, G_3, \ldots, G_k\}$ after ensuring that two nodes can be presented within a cluster if the OTF satisfies the threshold (*OTF_threshold*), as defined in Equation (4).

$$Initially \quad G_j = \{\ \} \tag{2}$$

$$n_i, n_j \in N \quad and \quad i \neq j,\ \exists OTF(n_i, n_j) \quad iff\ tr_{n_i, n_j} > 0 \tag{3}$$

$$G_k = \{G_k \cup \{n_i, n_j\} \mid OTF(n_i, n_j)\} \geq \text{OTF\_threshold} \tag{4}$$

3.4 Molecular Assembly

We have considered an existing single EN comprised of *M* nodes, whereby most of the outgoing traffic is routed through the backbone network. The heavy traffic through the backbone produces more carbon, thus posing threats to the environment. Molecular assembly (MA) works in similarity with the molecular assembly in nature, which goes over sequentially to discover various patterns of node assembly with a local interaction selected as the force of attraction. The MA algorithm illustrated in detail in Fig. 2, generates the multi-clustered enterprise network after passing through two phases; discovery and assembly. In discovery phase, the associations between the nodes are discovered with outgoing traffic selected as the force of attraction and the discovery phase is subdivided into intra-discovery and extra-discovery. Intra-discovery procedure starts exploring the nodes and it discovers the node-pair associations to generate the clusters, whereas extra-discovery procedure utilizes the prior knowledge. It combines the knowledge of present discovery of node assembly with the previous one to improve the solution. The algorithm ensures the discovery of associations among the node pairs before proceeding with the next the phase.

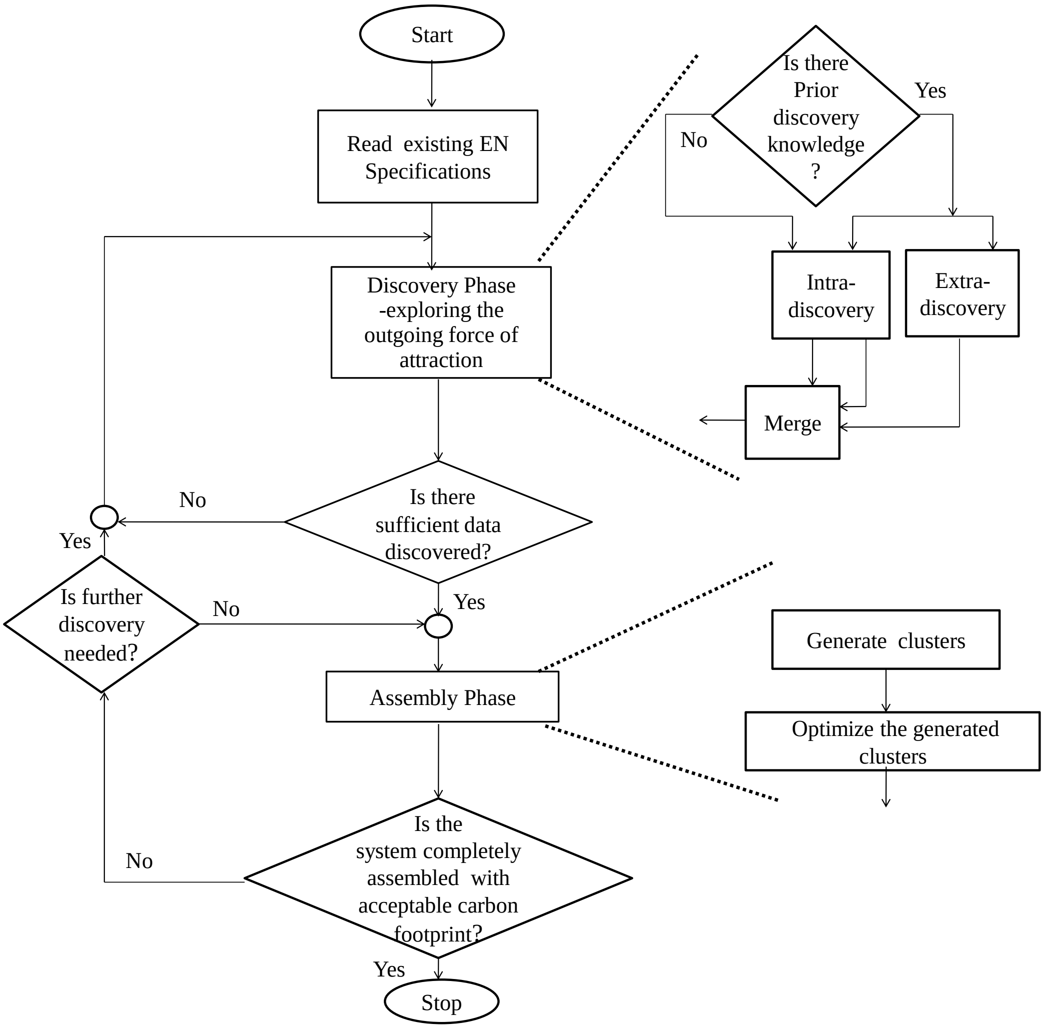

Figure 2. Molecular assembly.

In assembly phase, the associations discovered in previous phase are utilized to generate the cluster assembly and the cluster assembly is optimized by comparing the carbon footprint with the prior solutions. The MA algorithm goes repetitively and if necessary, it re-discovers the associations to produce cluster assembly with less carbon.

3.5 Carbon Footprint Estimation

The volume of carbon released into the atmosphere by the traffic flow at the backbone of an enterprise network is estimated using the relation between energy and carbon. The backbone traffic is segmented into packets or datagram suitable for transmission under TCP or UDP. Each packet or datagram is encoded using Manchester NRZ coding for transmission through physical layer. The normalized power consumed by the packet/datagram of a defined size is obtained by integrating the area under the generated power spectral density curve $P_w(f)$ [2] as explained by Equation (5), wherein, the power spectral density $P_w(f)$ is defined by Equation (6). Hereby, $W_T(f)$ is the Fourier transform of the transmitted current or voltage waveform $w_T(t)$ and $P_w(f)$ has a unit of W/Hz.

$$P = \int_{-\infty}^{\infty} P_w(f)df \tag{5}$$

$$P_w(f) \triangleq \lim_{T \to \infty} \left(\frac{|W_T(f)|^2}{T} \right) \tag{6}$$

With known transmission bit rate of $\frac{1}{T_b}$, the power spectral density of a Manchester NRZ signal [2] with unit amplitude and rectangular pulse is given by Equation (7):

$$P_{Manchester-NRZ}(f) = T_b \left(\frac{\sin(\pi f\, T_b/2)}{\pi f\, T_b/2} \right)^2 \sin^2(\pi f\, T_b/2) \tag{7}$$

The average power consumed by the traffic flow computed using Equations (5) and (7) is substituted in Equations (8) and (9) to estimate equivalent carbon emission. The energy, *E*, consumed per day in transmitting the encoded data is found by Equation (8) and is represented in unit of watt-hour. Further, the energy *E* is multiplied by an energy-carbon conversion factor of 0.184 per unit GHG emission [17] as in Equation (9) to compute day-to-day GHG emissions, whereby natural gas is considered as the source of electricity. The energy-carbon conversion factor represents the kilograms carbon-di-oxide equivalent per unit of fuel consumed.

Energy consumed per day = $E = \int_f P_{Manchester-NRZ}(f)df * T$ (8)

Amount of carbon emission per day = $E \times 0.184$ (9)

3.6 Network Problem Formulation

We have considered the initial enterprise network with a set of *M* nodes and with known traffic matrix. The main objective function is to reduce the total carbon emission at the backbone of the existing enterprise network, which is defined in Equation (10). It is assumed that the inter-cluster communications are through the backbone. Hereby, C_{n_i,n_j} represents the amount of carbon emission produced at the backbone by the traffic flow from node n_i to node n_j present in two different clusters G_k and G_l and $G = \{G_1, G_2, G_3, ..., G_k\}$ represents the set of *k* clusters generated after synthesizing initial network. However, the volume of carbon emitted from the initial single enterprise is represented as the sum of the carbon produced by the traffic flow between the nodes n_i and n_j through the backbone, as represented in Equation (11).

$$\text{Min} \sum_{\substack{n_i \in G_k \& n_j \in G_l \\ n_i \neq n_j \& k \neq l}} C_{n_i,n_j}, \ \forall n_i,n_j \in N \quad and \quad \forall G_k,G_l \in G \tag{10}$$

$$C_{initial} = \sum_{n_i \neq n_j} C_{n_i,n_j}, \quad \forall n_i,n_j \in N \tag{11}$$

In addition to the force constraints related to MA presented in Equations (2) to (4), we present additional constraints to govern the behavior of the framework in generating clusters with balanced node distribution. Constraint (12) states that the number of clusters presents at any time in the network should be bounded by a minimum of *2* to a maximum of *M/2*, where *M* is the total number of nodes in the given network.

$$2 \leq \sum_{k=1} G_k \leq \frac{M}{2} \tag{12}$$

Constraint (13) checks the clusters in EN and ensures that each node is bound to a single cluster, thus avoiding node duplication within the clusters, wherein $\alpha_{i,j}$ represents the binding of node *i* to cluster *j*.

$$\sum_{j=1}^{k} n_i * \alpha_{i,j} = 1, \qquad \forall n_i \in N \tag{13}$$

Constraint (14) is added to strengthen constraint (13) by guaranteeing that the total number of nodes present in all the clusters at any time should be equal to *M*.

$$\sum_{j=1}^{k} \left| G_j \right| = M \tag{14}$$

The balanced node distribution is ensured by constraint (15), which restricts the possibility of grouping most of the nodes within a single cluster, which may result in a worst possible clustering scenario with 2 nodes grouped in one cluster and the remaining nodes in the second cluster.

$$2 \leq \sum_{\substack{j \in G_k \\ 1 \leq i \leq m}} n_i * \alpha_{i,j} \leq \frac{M}{2} \quad \text{for} \quad j = 1,2,\ldots,k \tag{15}$$

4. Procedure for Comparative Study

We have devised a procedure to estimate the carbon footprint from transport layer to physical layer, which is illustrated in Fig. 3. The procedure starts by reading the backbone traffic of the existing network and then, it estimates the initial carbon footprint after packetizing the data satisfying the constraints of the transport layer protocols, the QoS of the transmission link and also the encoded transmission through the physical layer. The difference in the header length of TCP and UDP and the efficiency of the transmission line limit the payload size, thereby alter the number of packets produced for a specified volume of data. The carbon footprint during the transmission of packets through the physical layer is computed using the power spectrum of Manchester coding.

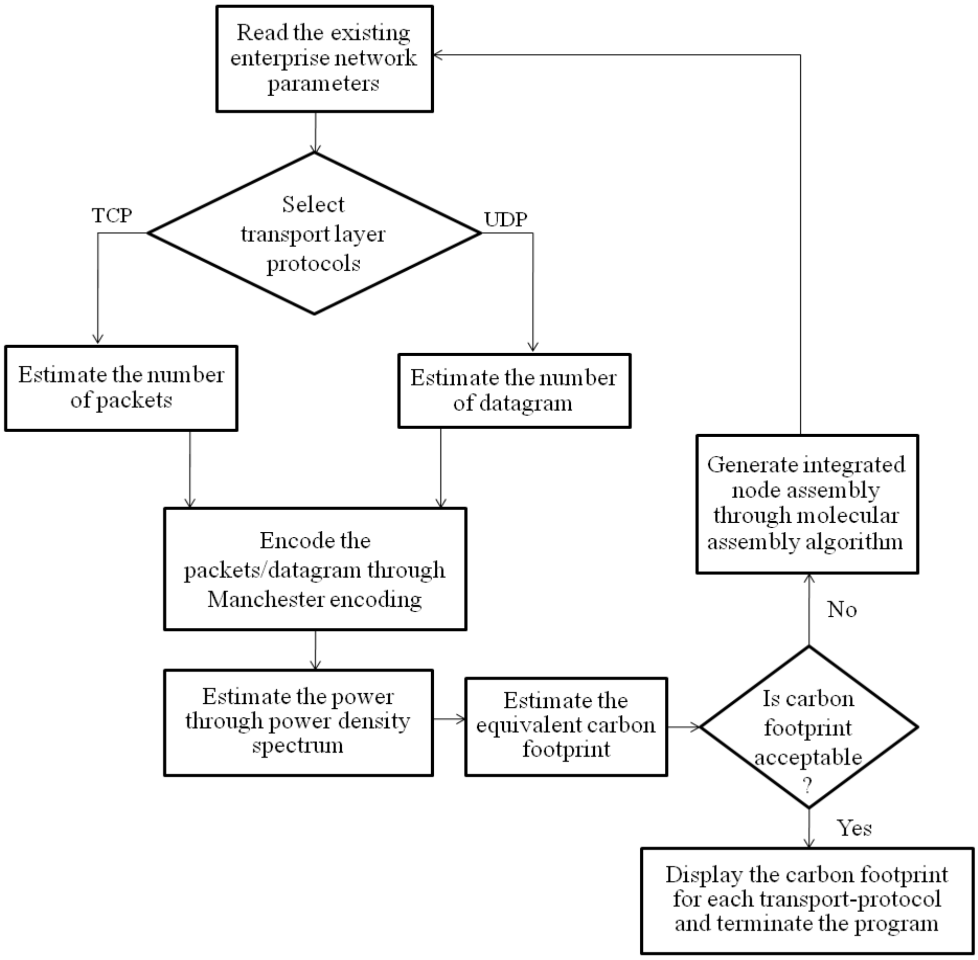

Figure 3. Comparison of communication protocols.

Later on, the procedure employs bio-inspired molecular assembly technique to integrate the associated nodes together into a single cluster. The integrated node assembly increases the local traffic, consequently the backbone traffic reduces. The node assembly generation is optimized within MA, which is detailed in section 3.2. The carbon emission produced at the end of each of the iteration is compared with the prior solutions corresponding to the selected protocol and the cluster assembly with reduced carbon emission is considered to be the best solution.

5. Results and Discussion

We have carried out ten sets of experiments to illustrate various carbon producing scenarios in the transmission of backbone data from transport layer to physical layer, whereby QoS of the transmission link and communication protocols at the transport layer are varied. The given single enterprise network with 100 nodes, producing different external traffic volumes of 650 MB, 1 GB and 4 GB is considered as an initial network. The QoS of the transmission line is varied from 100% to 20%. The Ethernet transmission frame format with UDP payload size of 1472 bytes and TCP payload size of 1460 bytes is selected for transmission.

The data packets are encoded using Manchester coding while transmitted through physical layer and the power density spectrum of the transmitted packets, which is shown in Fig. 4, are computed for varying data lengths. It is observed from the graph that the width of the power spectrum grows with the data length. The power spectrum is then integrated over the specified frequency interval to estimate the average power consumed by the transmission.

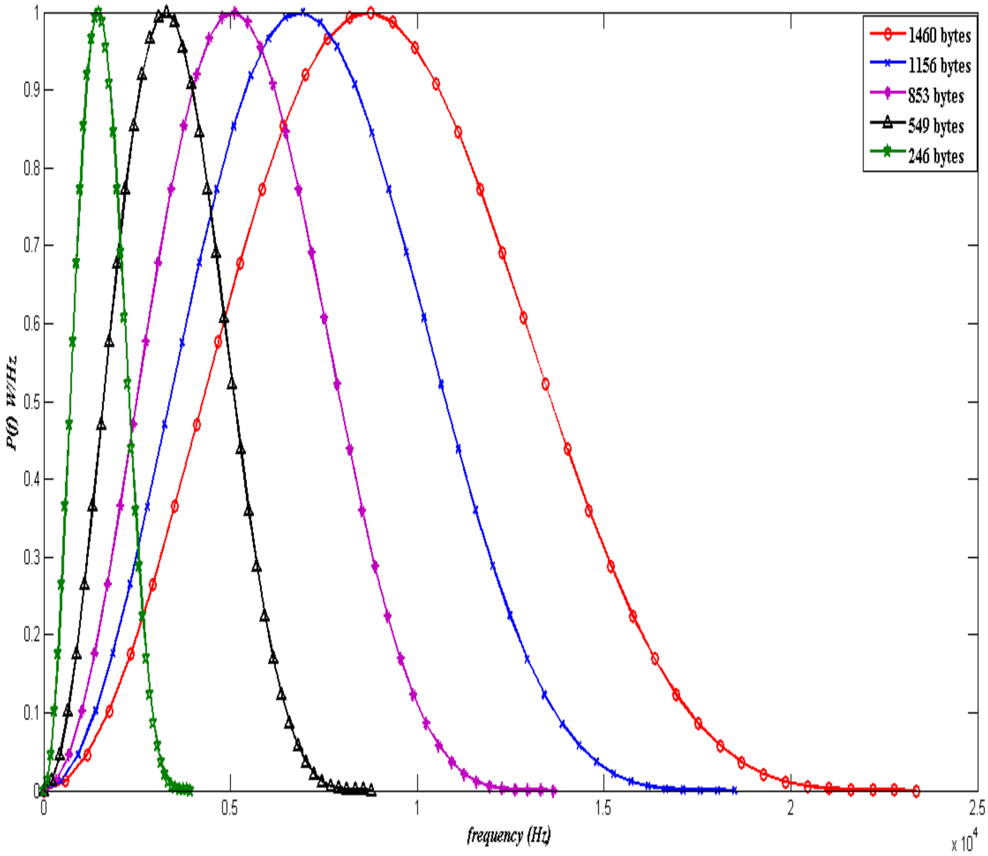

Figure 4. Power density spectrum of various volumes of data encoded within Manchester coding.

5.1 Existing Enterprise Network

The experiment is started with the simulation of single enterprise network with known traffic pattern. The behavior of initial network is analyzed against the two transport layer communication protocols TCP and UDP by comparing the number of packets generated utilizing the transmission link with single QoS. This experiment is mainly conducted to analyze the number of transmissions in each of the category, which is later related to the carbon emission. Furthermore, the experimental setup is varied by providing transmission line with a combination of multiple QoS factors, thereby generating packets of non-uniform length. The carbon footprint is recorded for both the communication protocols (TCP and UDP) utilizing uniform transmission rate with backbone traffic of 650 MB. Hereby, the QoS of the link is varied from 100% to 20%. The carbon emissions corresponding to TCP are listed in Table 1 and the carbon emissions corresponding to UDP are listed in Table 2. It is observed from the tables that for a transmission link with single QoS, the annual carbon footprint corresponding to TCP and to UDP are nearly equal. However, the annual carbon emission increases with decreasing QoS and is resulted from the increase in the number of generated packets and the number of transmissions.

In Table 1 and Table 2, column 3 details the actual size of the packet transmitted with TCP and UDP and column 4 describes the number of packets generated, which is found to be increasing with decreasing QoS. It is observed that the annual carbon footprint increases by 79% as the QoS decreases from 100% to 20%.

Table 1. Annual carbon footprint with TCP as a transport layer protocol.

QoS	Packet size (bytes)	TCP-data Payload (bytes)	Number of packets generated by TCP	Carbon footprint per packet/year (kg)	Total annual carbon footprint (kg)
100	1518	1460	445206	0.1524	67.849
80	1214	1156	562284	0.1498	84.230
60	911	853	762017	0.1353	103.101
40	607	549	1183971	0.1280	151.548
20	304	246	2642276	0.1252	330.813

Table 2. Annual Carbon footprint with UDP as a transport layer protocol.

QoS	Packet size (bytes)	UDP-data Payload (bytes)	Number of packets generated by UDP	Carbon footprint per packet/year (kg)	Total annual carbon footprint (kg)
100	1518	1472	441576	0.1529	67.517
80	1214	1168	556507	0.1502	83.587
60	911	865	751446	0.1361	102.272
40	607	561	1158645	0.1298	150.391
20	304	258	2519380	0.1286	323.992

The traffic pattern of the EN is varied to produce an external traffic of 1 GB at the backbone and the outcome of the experiment is tabulated in Table 3. From the data in column 3 and column 6, it is concluded that higher quality transmission link with 100% bandwidth utilization produced less carbon than the link with 20% utilizations. On comparing the total carbon footprint for backbone traffic of 650 MB with that of 1 GB, it is understood that the increase in traffic increases the number of transmissions, which increases the carbon emission.

Table 3. Carbon footprint of an enterprise with 1 GB backbone traffic.

Maximum packet size (UDP) (bytes)	Number of Packets	C per year (kg)	Maximum packet size (TCP) (bytes)	Number of packets	C per year (kg)
1460	679347	103.87	1472	684931	104.38
1156	856164	128.59	1168	865051	129.58
853	1156069	157.34	865	1172332	158.62
549	1782531	231.37	561	1821493	233.15
246	3875968	498.45	258	4065040	508.94

5.2 Optimization within MA

Second set of experiments are carried out within MA to observe the reduction in carbon emission at the backbone of EN. Hereby we have increased the outgoing traffic at the backbone of to 4 GB. By integrating the associated nodes together into suitable clusters, MA reduces the traffic by 64.5%. The behavior of ideal network with 100% QoS within MA is plotted against the two communication protocols in Fig. 5. The initial stages of MA produces a marginal carbon reduction of around 5%, whereby TCP produces slightly higher carbon than UDP. However, the repeated optimization produces considerable reduction in carbon footprint by 63%.

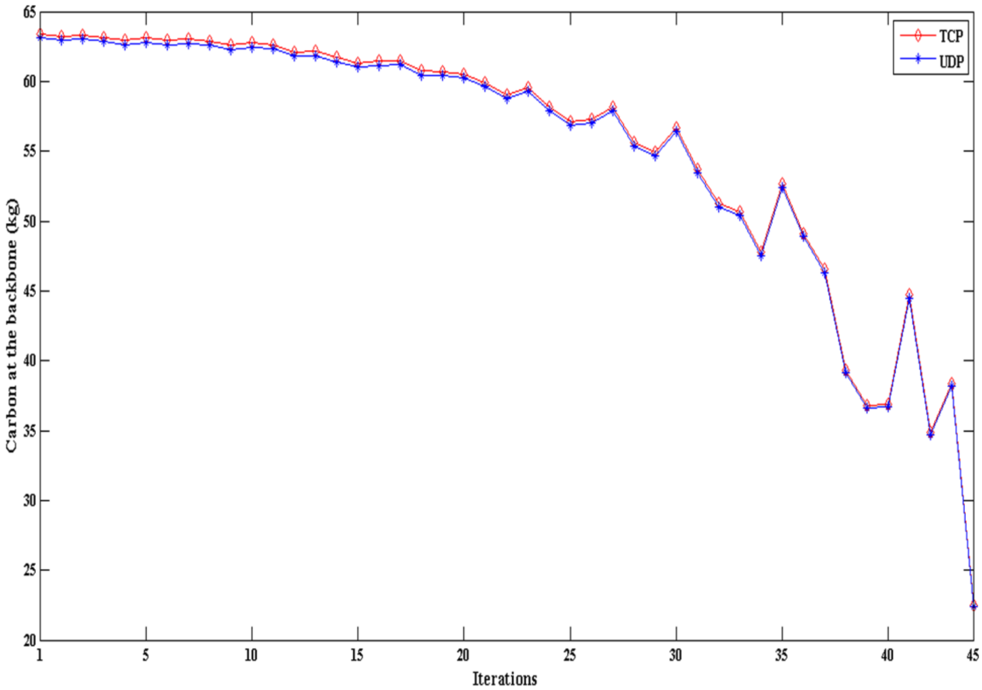

Figure 5. Comparison of TCP and UDP against carbon emission under uniform transmission rate.

The experiment is repeated for a transmission link with varying QoS, whereby three different transmission rates are selected for transmitting the generated data at the backbone. The generated backbone traffic is segmented into three portions; 50%, 25% and 25%.

Subsequently, transmission link with 100%, 80% and 20% QoS are utilized in transmitting the data segments respectively. MA manages to reduce the initial backbone traffic of 4 GB to 1.7 GB by generating suitable clusters. The cumulative sum of the carbon produced in transmitting the entire packets, considering TCP and UDP are plotted in Fig. 6. It is observed from Fig. 6 that UDP performs better by consuming 13.7% less carbon than the TCP during initial stages of MA. Later on, the gap between the two graphs reduces and finally, UDP based transmission ends with 10% less carbon than TCP based communications.

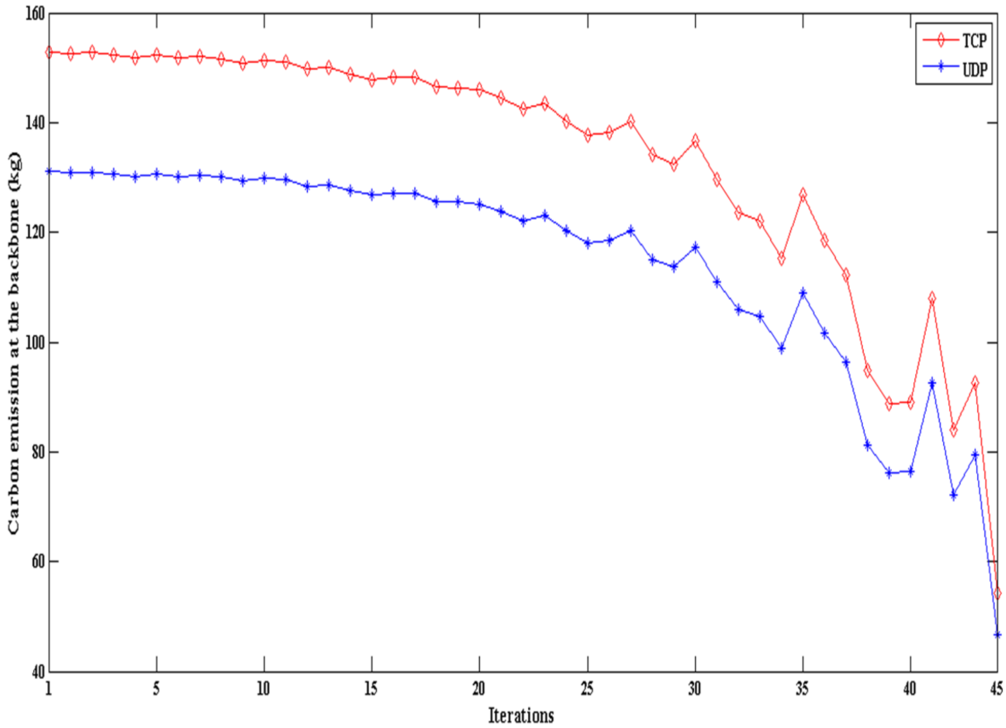

Figure 6. Comparison of TCP and UDP against carbon emission under varying QoS.

6. Conclusion

We have estimated the carbon footprint in transmitting data from transport layer to the physical layer within an enterprise network. We have compared the estimated carbon volumes against the two communication protocols TCP and UDP, whereby the comparative study considers three factors such as the de facto size of the packet associated with the selected protocol, the quality of the transmission link, and the data encoding schemes. The power spectrum of the transmitted packet is integrated over a specified frequency interval to estimate the carbon footprint. Furthermore, the backbone traffic is optimized through molecular assembly to enable reduced carbon footprint within the enterprise, whereby MA integrates the associated nodes into suitable clusters to reduce the number of transmissions. The simulation result for a typical enterprise with 100 nodes generating backbone traffic of around 4 GB using Ethernet transmission frame shows that the data transmission using UDP produces a total of 63.26 kg of carbon volumes and using UDP produces a total of 63.03 kg carbon under uniform transmission rate. The difference in carbon footprint between UDP and TCP based transmissions increases up to 14% for non-uniform transmission rate, whereby UDP based transmission within MA shows a maximum reduction of 64.5% than the initial network.

Acknowledgement

This work was supported by Kuwait University, Research Grant No. EO 02/11.

References

[1] L. L. Peterson and B. S. Davie, "Computers Network: A Systems Approach," Elsevier Publications, USA, 2005.

[2] Leon W. Couch, II, "Digital and Analog Communication Systems," Pearson International Edition, USA, 2007.

[3] Heylighen, F., and Gershenson, C., "When Can We Call a System Self-organizing?" In the Proceedings of 7th European Conference on Artificial Life, Dortmund, Germany, LNAI 2801, Springer-Verlag, pp. 606-614, 2003. http://dx.doi.org/ 10.1007/978-3-540-39432-7_65

[4] Giannoulis, S., Antonopoulos, C., Topalis, E., Athanasopoulos, A., Prayati, A., and Koubias, S., "TCP vs. UDP Performance Evaluation for CBR Traffic On Wireless Multihop Networks," In the Proceedings of Communication Systems, Networks and Digital Signal Processing, 19-21 July 2006, Patras, Greece.

[5] Garcia, N.M., Freire, M.M., and Monteiro, P.P., "The Ethernet Frame Payload Size and Its Effect on IPv4 and IPv6 Traffic," In the Proceedings of International Conference on Information Networking, 23-25 January 2008, Busan, Korea, pp.1-5. http://dx.doi.org/10.1109/ICOIN.2008.4472813

[6] Zhang, W., Hansen, K.M., Fernandes, J., Schütte, J., and Lardies, F.M., "QoS-Aware Self-adaptation of Communication Protocols in a Pervasive Service Middleware," In the Proceedings of IEEE/ACM International Conference on Green Computing and Communications, 18-20 December 2010, Hangzhou, China, pp.17-26. http://dx.doi.org/ 10.1109/GreenCom-CPSCom.2010.132

[7] Rind, A.R., Shahzad, K., and Qadir, M.A., "Evaluation and comparison of TCP and UDP over Wired-cum-Wireless LAN," In the Proceedings of Multitopic Conference, 23-24 December 2006, Islamabad, Pakistan, pp.337-342. http://dx.doi.org/10.1109/INMIC.2006.358188

[8] Koutitas, G., and Demestichas, P., "A Review of Energy Efficiency in Telecommunication Networks," Telecommunication Forum Journal, vol. 2, no. 1, 2010.

[9] Despins, C., Labeau, F., Tho Le Ngoc, Labelle, R., Cheriet, M., Thibeault, C., Gagnon, F., Leon-Garcia, A., Cherkaoui, O., St. Arnaud, B., Mcneill, J., Lemieux, Y., and Lemay, M., "Leveraging green communications for carbon emission reductions: Techniques, Test beds, and Emerging Carbon Footprint Standards," IEEE Communications Magazine, vol.49, no.8, pp.101-109, August 2011. http://dx.doi.org/ 10.1109/MCOM.2011.5978422

[10] Peng, R., and Wang, X., “ICT Solutions Calculation Model for CO2 Emission Reduction and Prediction on Its Emission Reduction Potential,” In the Proceedings of International Conference on Management and Service Science, 20-22 September 2009, Beijing, China, pp.1-5. http://dx.doi.org/10.1109/ICMSS.2009.5301630

[11] Ross Ashby, W., “Principles of Self-Organizing System,” Principles of Self-Organization: Transactions of the University of Illinois Symposium, 8-9 June 1961, Illinois, USA, pp. 255-278.

[12] Habib, S.J., and Marimuthu, P.N., “Molecular Assembly Tool for Synthesizing Multi-tier Computer Networks,” In the Proceedings of 23rd IEEE International Conference on Tools with Artificial Intelligence, 7-9 November 2003, Boca Raton, Florida, USA. (Poster). http://dx.doi.org/10.1109/ICTAI.2011.141

[13] Habib, S.J., and Marimuthu, P.N., “Capacity Planning for Enterprise Green Communications,” In the Proceedings of Second International Conference on Green Communication and Networking, 25-26 October 2012, Gandia, Spain.

[14] Habib, S.J., and Marimuthu, P.N., “Carbon Offsetting through Computer Network Redesign,” In the Proceedings of International Conference on Information Networking, 1-3 February 2012, Bali, Indonesia. (Poster) http://dx.doi.org/ 10.1109/ICOIN.2012.6164415

[15] Habib, S.J., and Marimuthu, P.N., and Zaeri, N., “Green Communications through Network Redesign,” In the Proceedings of First International Conference on Advances in Computing and Communications, 22-24 July 2011, Kochi, India. http://dx.doi.org/10.1007/978-3-642-22714-1_36

[16] Ray Horak, “Communications Systems and Networks,” Wiley Publications, USA, 2002.

[17] Carbon Footprint Conversion Factors: http://archive.defra.gov.uk/environment/business/reporting/pdf/101006-guidelines-ghg-conversion-factors.pdf