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Transferrable Payoff Based Bandwidth Allocation for Small and Medium Enterprises

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Abstract: Most Small and Medium Enterprises (SMEs) setup wireless networks instead of wired networks in order to make the process of communicating and sharing resources among their employees easier, more flexible, faster, cheaper and more ubiquitous. Furthermore, as the SMEs tend to grow in terms of its number of employees, the additional employees create the need for increased number of wireless communication terminal devices such as PCs, PDAs, iPads, etc. which are mostly used by employees to efficiently and effectively accomplish their workplace tasks. However, increasing the size of wireless communication devices constrains the scarcely available spectrum bandwidth. As a result, there exist bandwidth allocation inefficiency, high network latency, link congestion and high number of lost packets. Similar studies have attempted allocating bandwidth between the communicating users in uncooperative fashion, leading to inefficient bandwidth allocations and also not may not be suitable for a cooperative architecture of the SMEs considered in the current study. In order to enhance spectrum bandwidth allocation an integrated transferrable payoff coalitional game theory and standard-Dijkstra algorithm has been proposed in this study. This algorithm involves modelling of the spectrum bandwidth allocation problem in terms of an integrated transferrable payoff coalitional game and the least load shortest path model. The Dijkstra-Transferrable Payoff (DTP) algorithm is then proposed to solve the formulated model. Several computer simulations showed that the proposed algorithm provides reduced link congestion an end-to-end delay and a minimized number of lost packets at various packet sizes of the network injected traffic when compared to the standard-Dijkstra algorithm and Game-Theoretic Bandwidth Allocation (GTBA) algorithm.

Key words: Wireless networks, transferrable payoff coalitional game theory, standard-Dijkstra algorithm, Small and Medium Enterprises (SMEs), QoS, Dijkstra-transferrable payoff algorithm

INTRODUCTION

Over the past period we have seen many enhancements in physical-layer wireless communication theory and their implementation in wireless network systems. Such improvements have enabled wireless network technologies to receive a greater market acceptance all over the world. This is partly due to the fact that wireless network operations permit services such as long-range communications through radio communication or signals (Mathonsi and Kogeda, 2014a,b; Ali *et al*., 2016).

Wireless Local Area Networks (WLANs) has extended or replaced wired Local Area Networks (LANs) in both infrastructure and ad-hoc configurations over the past years. This is mainly because WLANs use short-range wireless technologies such as Wireless Fidelity (Wi-Fi) as opposed to the use of network cables to provide users with access to the internet. Currently, wireless technologies use 2.4 GHz Ultra High Frequency (UHF) and 5 GHz Super High Frequency (SHF) radio waves to transmit packets over a WLAN. This has allowed WLAN users to transcend time and place of work, thereby increasing their work productivity (Mathonsi and Kogeda, 2014a, b; Ali and Hassan, 2016).

Although, the current WLAN speeds are less than the speed of wired Ethernet, WLANs offer a quick and inexpensive way to set up LANs because cabling is not neede WLAN users also get additional benefits such as: more efficient use of office space, increased network flexibility, lower network support and network maintenance costs. This is why many Small and the Medium Enterprises (SMEs) across the world including South Africa have implemented wireless networks (Mathonsi and Kogeda, 2014a, b).

Wireless network is considered to be good and successful if it offers good QoS because users always demand good QoS from their wireless network systems.

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However, this is not always what South African SMEs get from their wireless network systems. This is mainly, because the available bandwidth is not properly shared between the communicating users (Mathonsi and Kogeda, 2014a, b).

Similar studies have attempted allocating bandwidth between the communicating users in uncooperative fashion, leading to inefficient bandwidth allocations and also not may not be suitable for a cooperative architecture of the SMEs considered in the current study. Additionally, multiple exiting bandwidth allocation methods that assign bandwidth cooperatively, separates bandwidth allocation procedure and path selection process. As a result we end up with bandwidth allocation inefficiency, high network latency, link congestion and high number of lost packets. In order to meet the users QoS demand we designed and implemented an enhanced bandwidth sharing scheme by integrating the transferrable payoff coalitional game theory and the standard-Dijkstra algorithm. The new designed algorithm has been named Dijkstra-Transferrable Payoff (DTP) algorithm. The DTP algorithm introduces transferrable payoff coalitional game theory into hop by hop routing and channel bandwidth allocation. The integration on the proposed DTP algorithm did not add computational complexity in the sense that rather than splitting the processes and experiences additional computational duty cycles, we merge the processes into one and execute the resulting functionality using one duty cycle. As a result, the time taken to select best paths in a network and for bandwidth allocation has been reduced through merging of the two processes. This is an improvement on previous work done by Massoulie and Roberts (1999), Kadri and Zouari (2014). As an outcome, the QoS of layer 2 of the network protocol stack has greatly improved by selecting a more reliable path with least short path, link load and less link interference. Furthermore, it improves the performance of layer 3 by allocating the available bandwidth between communicating users based on traffic type they want to send at a particular time.

The DTP algorithm uses transferrable payoff coalitional game theory first to control bandwidth sharing then standard-Dijkstra algorithm is used to select the best route with least load, shortest path and less link interference. When applying transferrable payoff coalitional game theory, we prioritize packets where high-bandwidth traffic had high priority over low-bandwidth traffic.

The main contribution of this study with respect to Massoulie and Roberts (2002), Kadri and Zouari (2014) is the derivation of a fair cooperation and bandwidth allocation strategy between communicating users. The strategy is based on the traffic type that a user chooses to send at a particular time. Moreover, this strategy allows the user to select a more consistent path before the packet transmission than the previous related research by Massoulie and Roberts (1999), Kadri and Zouari (2014) (Table 1).

Table 1: Notations

Notations	Variables
S	All possible coalitions
V	Coalition value
N	Set of players
i	Node (user)
v(S)	Is the amount of utility that the coalition can be divided between its members (users)
v(N)	The sum of the expected marginal contributions after coalition between users
x(S)	Is the amount of utility that can be divided between users without coalition
x(N)	The sum of the contributions without coalition between users
V	Number of vertices
D_P	Processing delay
D_T	Transmission delay
D_p	Propagation delay
D_{E2E}	Average end-to-end delay
BW_N	Allocated bandwidth to users after coalition

Literature review: Over the past years a lot of research has been done on bandwidth sharing schemes, protocols and algorithms in order to optimize the utilization of the available bandwidth in a wireless network (Ali *et al*., 2016).

Game-Theoretic Bandwidth Allocation (GTBA) algorithm was proposed by Massoulie and Roberts (1999). The GTBA algorithm uses call control mechanism to allocate the available bandwidth between communicating users/nodes. QualNet simulator was used to test their solution. QualNet simulation results showed that GTBA reduced link congestion, however, there was still a possibility of experiencing high end-to-end delays, because GTBA is not able to select a reliable path with a low link load and less link interference before the commencement of a packet transmission.

Kadri and Zouari (2014) proposed a Dijkstra algorithm that firstly calculate the dynamic reliability of the valves engaged to open (openers) and to close (closers) in the path's search according to their behavior and secondly to find an optimal path. MATLAB was used to simulate their solution. MATLAB solution results showed that their algorithm chose the best shortest path in a wireless network, however, their solution did not allocate the available bandwidth based on traffic type as bandwidth was allocated dynamically between communicating users. The proposed DTP algorithm did not only select the best shortest path, it also selected the best path with minimum link load and less link interference and allocated high bandwidth to high-priority traffic and low bandwidth to lower-priority traffic, this reduced end-to-end delays inwireless network.Kim proposed the use of interactive decision theory using Rubinstein-Stahl Model as a bandwidth sharing mechanism. Rubinstein-Stahl Model allocates bandwidth based on bargaining power. Users with more bargaining power benefited more from their bargaining power and resulted to bandwidth partitioning problem. The simulation results showed that end-to-end delays were reduced when Rubinstein-Stahl Model was applied in a network but their model failed to select the best path with least link load and less link interference. The proposed DTP algorithm reduced end-to-end delays by selecting a path with low link load and less link interference. Moreover, by allocating high bandwidth to high-priority traffic and low bandwidth to lower-priority traffic.

Niyato and Hossain (2006a, b) proposed cooperative and non-cooperative game based allocation schemes. In their first scheme they modelled the bandwidth allocation problem as a bankruptcy game and Shapley value was used to determine the amount of bandwidth that each player (users/nodes) should be allocated. Dummy players were assigned zero payoffs when Shapley value was used to allocate the available bandwidth between communicating users however, this increased end-to-end delay. In their second scheme; Nash equilibrium was used to allocate bandwidth between communicating users, this reduced end-to-end delay but failed to allocate the available bandwidth fairly. Whereas, the proposed DTP algorithm allocated the available bandwidth to nodes based on the type of traffic a node wants to send. In the event that a high-bandwidth traffic has higher priority over low-bandwidth traffic then a path is selected with least link load and interference in order to reduce end-to-end delay while providing better QoS.

Kumar *et al.* (2013) proposed bankruptcy game based bandwidth allocation mechanism and Kalai Smorodinsky bargaining solution to determine the appropriate bandwidth allocation vector. The simulation results showed that the QoS produced by the network improved slightly, however, their scheme failed to select a path with low link load and less link interference which increases end-to-end delay. Instead, the proposed DTP algorithm is able to reduce an end-to-end delay by first controlling bandwidth allocation and then selecting the shortest path with less link load and interference which GTBA algorithm failed to achieve.

Ramaboli proposed the use of least number of Radio Access Technologies (RATs) for bandwidth allocation between communicating users in a wireless network. The use of RATs reduced energy consumption and synchronization overhead on the receiving multi-homed terminal since only a small number of interfaces need to be activated to serve the request in order to maximize bandwidth allocation. Their solution cannot select the shortest path with least link load and less link interference. The proposed DTP algorithm maximized bandwidth utilization by allocating higher bandwidth to high-bandwidth traffic. Additionally, low-bandwidth traffic was allocated lower bandwidth, this was in order to provide better QoS. Moreover, the shortest path with least link load and less link interference was selected before packet transmission.

Fang and Bensaou (2004) proposed to use Utility-based Multi-Service Bandwidth Allocation (UMBA) algorithm in order to improve the performance of wireless network. UMBA algorithm uses the utility fairness to allocate bandwidth between communicating users/nodes without knowing the capacity of the whole network. They implemented and tested their algorithm using NS-2. The simulation results showed that UMBA algorithm reduced the number of packets lost during transmission than evolutionary game theory and Simultaneous games theory. The use of UMBA algorithm reduced the number of lost packets during transmission however, bandwidth allocation between communicating users remained as a problem with their solution. As a result, DTP algorithm introduced the use of transferrable payoff coalitional game theory to solve a hop by hop routing and channel bandwidth allocation problem.

Mathur *et al.* (2008) proposed the use of Grand Coalition (GC) scheme for bandwidth allocation. Where bandwidth allocation depends on the manner in which the rate gains are apportioned among the cooperating users. In their GC scheme for maximum gains users may prefer to cooperate with a selected set of users to form coalitions that are closed to cooperation from users outside the group. NS-2 was used to implement and test the performance of their GC scheme in a wireless network. The simulation results showed that when GC scheme was used there is high utilization of available bandwidth and the network produced better QoS. Their solution used the standard procedure of selecting the shortest path which resulted to end-to-end delay during packet transmission. The proposed DTP algorithm used transferrable payoff coalitional game theory to first control bandwidth sharing where high-bandwidth traffic had high priority over low-bandwidth traffic. The DTP algorithm then applies the standard-Dijkstra algorithm to select the route with least load and shortest path. This improved the QoS as end-to-end delay was reduced during packet transmission.

Singh *et al.* (2012) proposed that services providers cooperate by jointly deploying and pooling their resources such as spectrum and infrastructure (e.g., base stations) and agree to serve each other's customers, their aggregate payoffs and individual shares, may substantially increase through opportunistic utilization of resources. The potential of such cooperation can, however, be realized only if each provider intelligently determines with whom it would cooperate, when it would cooperate and how it would deploy and share its resources during such cooperation. Also, developing a rational basis for sharing the aggregate payoffs was imperative for the stability of the coalitions. This increased bandwidth utilization and provided better QoS to mobile users, however, their solution did not give high bandwidth traffic higher priority over low bandwidth traffic during packet transmission. The proposed DTP algorithm improved bandwidth utilization by giving high bandwidth traffic higher priority over low bandwidth traffic in order to minimize end-to-end delay between communicating users.

As the literature reviewed has shown that the performance improvement of wireless networks has been witnessed at separate layer 2 and 3. However, several performance issues such as high end-to-end delay, high network latency and high number of lost packets caused by using hop by hop routing, inefficiency bandwidth allocation have been noted. In contrast, the proposed DTP algorithm in this study enhances the identified shortcomings by introducing transferrable payoff coalitional game theory into hop by hop routing and channel bandwidth allocation.

In DTP algorithm, we modeled spectrum bandwidth allocation objective as transferrable payoff coalitional game, followed by finding the shortest path between the source and destination nodes with the least link load and less link interference. Based on the simulation results, the proposed DTP algorithm showed reduced link congestion, end-to-end delay and minimized number of lost packets at various packet sizes in the network as compared to standard-Dijkstra algorithm and GTBA algorithm.

MATERIALS AND METHODS

Small and medium enterprises: Research indicates that SMEs in South Africa are a major provider of the employment and contribute significantly to the growth of Gross Domestic Product (GDP). In South Africa, SMEs are the main source of most innovation and new products. However, South African SMEs face challenges such as shortage of business and technical skills, difficulty in access to international markets, start-up capital, operating finance and increasing competition. SMEs also have advantages over large companies including, most time is spent on activities that are directly client-related, more innovative and less bureaucratic.

SMEs are usually defined in terms of the number of employees they have or turnover (profit) they make. SMEs are not restricted to pay Value-Added Tax (VAT), however, if their annual profit exceed R150 000 they are registered to pay VAT. SMEs definition in terms of employment is presented using Table 2.

Table 2: Definition of SMEs

SME types	No. of employees
Very small organization	1-10
Small organization	11-50
Medium organization	51-120

According to, the Department of Trade and Industry (DTI), SMEs are registered as private companies, close corporations or co-operative enterprises with the Companies and Intellectual Property Registration Office (CIPRO).

SMEs setup wireless networks for the purpose of communication and sharing resources, mainly because WLAN users also get additional benefits such as: more efficient use of office space, increased network flexibility, lower network support and network maintenance costs (Mathonsi and Kogeda, 2014a, b).

Transferable payoff coalitional game: Cooperative games differ from non-cooperative games in that binding agreements are possible before the start of the game to allow game players of mutual interest apply common strategies. The basic notions defining a cooperative game are the set of players, the action sets and the payoffs. The value to a coalition is what it can achieve by coordinating their actions in order to achieve a common objective. A coalitional game (Niyato and Hossain, 2006a, b) consists of a set of players $N = \{1, 2, ..., Play_n\}$ that can form cooperative groups known as coalitions in order to strengthen their positions in the game. Any coalition $S \subseteq N$ represents an agreement between the players in S to act as a single entity, cooperate in their actions and earn shared payoff. The formation of coalitions or alliances is ubiquitous in many applications. For example, in political games, parties or individuals can form coalitions for improving their voting power. However, it is difficult to apply transferrable payoff game in a larger organization because competition is very high due to the fact that a user makes decisions that benefit him/her only.

In addition to the player set , the second fundamental concept of a coalitional game is the coalition value. Mainly, the coalition value, denoted by quantifies the worth of a coalition in a game. The definition of the coalition value determines the form and type of the game. Nonetheless, independent of the definition of the value a coalitional game is uniquely defined by the pair (N, v). It must be noted that the coalition value (v) is in many instances, referred to as the game, since for every coalition value (v) a different game may be defined. Each

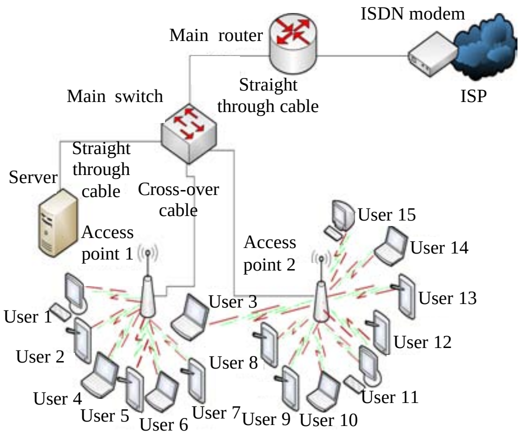

Fig. 1: Typical SME of 15 users/nodes

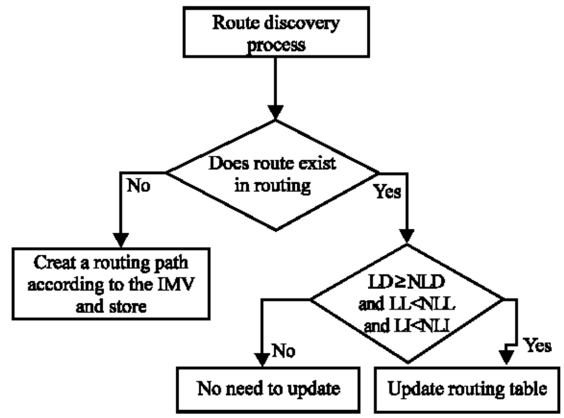

Fig. 2: Route discovery process

coalition has a value which quantifies its worth in the game (Massoulie and Roberts, 1999; Kumar *et al*., 2013).

In a graph form, the value of a coalition S depends on how the members of are connected in a graph (network), since the players are interconnected and communicate through pairwise links in a graph (network) (Niyato and Hossain, 2006a; Kumar *et al*., 2013). In a partitioning form, the value of a coalition depends on the partition of N that is in place at any time during the game. In such games, unlike the characteristic form, the value of a coalition S has a strong dependence on how the players in N/S are structured (Niyato and Hossain, 2006 a,b). In a characteristic form, the coalition value of any coalition S belonging to N and the coalition value depend on the traffic type a user wants to send at particular time and the available bandwidth (Massoulie and Roberts, 1999; Kadri and Zouari, 2014).

System design and architecture: We illustrated a normal SME wireless network traffic scenario which started with 8 users then grow to 15 users/nodes in Fig. 1.

The system architecture illustrated by Fig. 1 indicates that a user's machine (node) does not use a hop count metric to establish a communication. This is indicated by User 3 which is closer to access point 1 signals. However, User 3 uses access Point 2 as its communication path instead of access Point 1. User 3 first checks the link load and interference of each path in a network. Thereafter, selects a path with least link load and interference in order to avoid bottlenecks in the network. This reduced high end-to-end delay and high percentage of packets lost during packet transmission.

Router discovery process: In our proposed DTP algorithm a shortest path with the least link load and less link interference is selected in order to provide better QoS, the process of how the best path is selected is discussed. When a node desires to communicate with other nodes, it first checks its routing table for a route. Subsequently, the node always creates or updates a reverse route to the source Internet Protocol (IP) address in its routing table. If a route to the source IP address already exists it is updated only if either the source sequence number in the Route Request (RREQ) is higher than the destination sequence number of the source IP address in the route table or the sequence numbers are equal but the Integrated_Metrics_Value (IMV) in RREQ is smaller than the Prev_Integrated_Metrics_Value (PIMV) in the routing table. The new integrated_metrics_value is calculated by using Eq. 1:

$$M_N = \left(\left(C/C_{PE}\right) + \left(T/T_P\right) + \left(H/H_P\right)\right) \quad (1)$$

Previous_integrated_metrics_value is calculated by using Eq. 2:

$$M_p = C_{PE} + T_P + H_P \quad (2)$$

When a node wants to send a reply packet to the source, it first checks the routing table for collecting route information. The forward route for the destination is created or updated only if the destination sequence number in the Route Reply (RREP) is greater than the node's copy of the destination sequence number or the sequence numbers are the same but the route is no longer active. Route discovery process flow chart of is illustrated in Fig. 2. Where it shows how the shortest route with the least link load and less link interference is selected by comparing the Link Distance (LD) with Newly LD (NLD), Link Load (LL) with Newly LL (NLL) and Link Interference (LI) with Newly LI (NLI).

In this study, link load has been calculated by using Eq. 4 where all packets per link were added together to form a link load. The packets per link were calculated from $P_1, P_2, \ldots, P_n$, therefore, the link load is given by Eq. 3:

$$L = P_1 +, P_2 +, ..., +P_n \quad (3)$$

Intra-flow interference exists if two links belonging to the same path work on the same channel and are located within each other's interference range, i.e., within $P_H(\geq 2)$ hops. We calculated the link interference using the concept of sub-path spanning P_H+2 hops, based on the observation that a link can potentially interfere with another link at most P_H+2 hops away. In general, a P_H path contains P_H-P_H-1.

Bandwidth allocation: We presented how the shortest path was selected in order to reduce end-to-end delay. In this study, we show how the available bandwidth was allocated between communicating users. In this study, packets with 100 bytes upwards were classified as high-priority traffic while packets with 50 bytes downwards were classified as low-priority traffic as given by Eq. 4:

$$\begin{aligned} &\text{if } P_n \geq 100 \\ &BW_H = \left(BW_{total} - \sum_i^N G_i^H \right) \text{elseif } P_n \leq 50 \\ &BW_L = \frac{BW_{total} - BW_H}{\sum_i^N R_i^M} \end{aligned} \quad (4)$$

This minimized packet delay and delay variation for high-priority traffic to ensure better QoS. Transferrable payoff coalitional game ensures zero interruption for high-priority traffic such as real-time voice packets.

However, in a network, utility, i.e., bandwidth is transferrable if one player can transfer part of its utility to another player after coalition among users. Such transfers are possible if the players have a common utility that is valued equally by all. Therefore, all user's payoff (allocated bandwidth) is not below what each user was going to get in absence of cooperation for all Eq. 5. In this case, the assumption implies that irrespective of the division of the coalitional payoff, members of the coalition enjoy the same total utility:

$$A = \{x(N) = v(N), x(S) \geq v(S), \forall S \subset N\} \quad (5)$$

A coalitional game with transferrable payoff consists of set N of players; a function v that associates with every non-empty subset S of N a real number v (s). An outcome for this game is a vector $x \in R|^{N|}$ called payoff vector. The payoff vector is feasible if x (N)≤v (N).

In order to reduce network performance limits mentioned in study, we integrated transferrable payoff coalitional game theory with standard-Dijkstra algorithm with the aim of improving wireless network performance that South African SMEs use at a minimum cost.

Standard-Dijkstra algorithm was introduced to solve the single-source shortest path problem in a network. This is the algorithm that computes the shortest paths in a graph with non-negative edge weights (Kadri and Zouari, 2014; Bauer *et al*., 2010). Transferable payoff coalitional game was developed to allocate bandwidth between communicating users based on the coalition agreement between users. In this game, bandwidth is transferable if one user can transfer part of its utility to another user, based on the priority of what the other user wants to do in the network (Niyato and Hossain, 2006a, b; Saad *et al*., 2009; Choi *et al*., 2010).

The integration was done mainly because the algorithm should be designed with considerations of the available bandwidth of the network and is able to select the shortest path with the least link load and less link interference (Algorithm 1). In this study, packets with 100 bytes upwards were classified as high-priority traffic while packets with 50 bytes downwards were classified as low-priority traffic. We only show the added features of the DTP algorithm.

Algorithm 1; Dijkstra-Transferrable ayoff algorithm
Initialization:

```
Dn: = dist [u]+lenght [u, v]
Ln: = L [u]+L[u, v]
LIN: = Li [u]+Li [u, v]
while x∉0
if Dn<dist [v]:
   dist [v]: = Dn
    previous [v]: = u
   else if Ln<L [v]:
         L [v]: = Ln
         previous [v]: = u
       else if LIN<Li [v]:
        Li [v]: = LIN
        previous [v]: = u
      end elseif
      end elseif
end if
returndist [], L[], Li []
previous []
if
A = {x (N) = v (N), x (S)≥ v(S), ∀S⊂N} and
x (N)≤v (N)//coalition agreement
While pn≥100
BWH = (Bwtotal- ∑_i^N Gi^H )
else if Pn≤50
      BWL = Bwtotal-BWH/ ∑_i^N Ri^M
      end elseif
    end while
  end if
return BWH [], BWL []
end while
```

This study presented the design of DTP algorithm in which the transferrable payoff coalitional game theory with standard-Dijkstra algorithm were integrated in order to select the best path with least link load and less link interference during packet transmission. Moreover, DTP algorithm improved bandwidth allocation where high priority traffic was allocated high bandwidth than low priority traffic. This was done in order to solve bandwidth allocation inefficiency problem provided by previous bandwidth allocation methods. The efficacy of the DTP algorithm was validated via. a computer simulation as described next in study.

RESULTS AND DICUSSION

Simulation results: We carried out simulations using IEEE 802.11 Model developed using Network Simulator-2 (NS-2) Version 2.35. A virtual machine running Linux 12.04 operating system with 512 RAM was used and NS-2.35 was installed. Tool Command Language (TCL) script was used in NS-2 to simulate network topology and C++ was used to simulate the three algorithms in this paper. A network topology of 500×400 m with 15 randomly located nodes was used to compare the three algorithms. Constant Bit Rate (CBR) traffic type with 10, 50, 100, 150 and 512 packet sizes were configured between communicating nodes (Fig. 3). The simulation was configured to start transmitting CBR packets at 0.5 sec and stop transmitting at 300 sec. Three algorithms were compared using the performance results gained and recorded in out-nam script of NS-2.35. The performance results gained were recorded in order to get the average of packet delivery ratio, end-to-end delay, number of packets lost during transmission and network throughput after several simulations.

In this study, we needed to build a simple network topology which includes mobile nodes communicating wirelessly. NS-2 becomes the choice of simulation environment. This is because it is easy to set up and it provides the necessary Graphical User Interface (GUI) which simulates IEEE 802.11 Module. NS-2 offers a wide simulation environment for protocols, network types, applications, data sources and traffic models (Mathonsi and Kogeda, 2014a, b). NS-2 is helpful in studying and examining the dynamic nature of communication networks, since it is a simple event-driven simulation tool. NS-2 Software separates the processing of data and control (Mathonsi and Kogeda, 2014a, b). Additionally, NS-2 allows modification and addition of new protocols or any other components to it, mainly because it is open source software. NS-2 also includes the Network Ani Mator (NAM) that provides a Graphical User Interface (GUI) and visualization of designed and simulated network (Fig. 3). The performance metrics analyzed in our simulations include.

Packet delivery ratio: Are packets that are delivered successfully from sender to destination compared to the number of packets the sender sent.

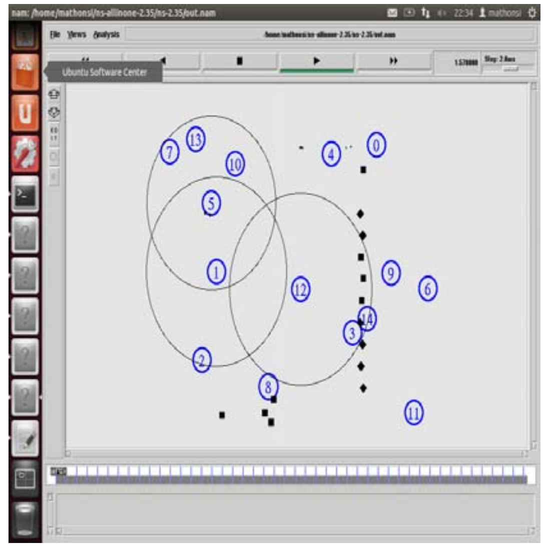

Fig. 3: NAM SME simulation scenario

Average end-to-end delay: Indicates how long it took packets to the reach the desired destination from the source.

Average percentage of packets lost: Is the number of packets lost during packet transmission.

Network throughput: Is the total amount of data successfully delivered from the sender to a receiver over a communication channel in a given time.

The performance evaluation was conducted on the mentioned metrics, mainly because these metrics were the main ones that we needed to improve on. Therefore, in order for us to see an improvement on the metrics mentioned, we had to do performance evaluation using computer simulation.

We compared the proposed DTP algorithm with standard-Dijstra algorithm (Kadri and Zouari, 2014) and GTBA algorithm (Massoulie and Roberts, 1999) in a network with 8 nodes before the number of network user's growths. Thereafter, we compared the three mentioned algorithms in a network with 15 nodes, this is after an SME has grown from 8 users to 15 users. This was done to support evidence of performance improvement when the proposed DTP algorithm was used in SME wireless network that grow. Standard-Dijstra algorithm was chosen because it does not support the shortest path with negative weight. The shortest path with negative weight leads to acyclic graphs and most often cannot obtain the right shortest path. When standard-Dijstra algorithm was used in a network, the available bandwidth was allocated

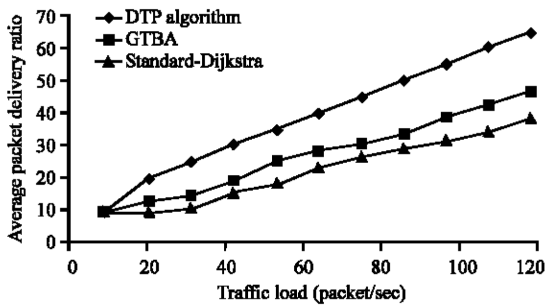

Fig. 4: Average packet delivery ratio for 8 nodes with DTP algorithm; packet delivery ratio for 8 nodes

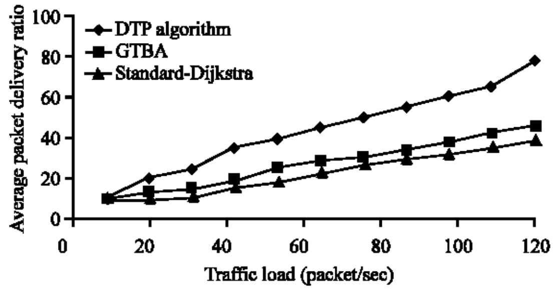

Fig. 5: Average packet delivery ratio for 15 nodes with DTP algorithm; packet delivery ratio for 15 nodes

dynamically between communicating users. GTBA algorithm was chosen because it uses call control mechanism to allocate the available bandwidth between communicating users. In GTBA algorithm users make decisions independently, this means that users do not wait for a decision that benefits all of them to be taken before they communicate. In the proposed DTP algorithm, the available bandwidth was allocated between communicating users based on the traffic type a user wants to send at a particular time and the algorithm also first finds a consistent path to transmit packets between communicating users. However, high-bandwidth traffic had high priority over low-bandwidth traffic (Mathonsi and Kogeda, 2014a, b).

Packet delivery ratio: Average packet delivery ratio obtained from the simulation results are presented in Fig. 4 and 5. Figure present the simulation results of the compared algorithms, namely, DTP algorithm, standard-Dijstra algorithm and GTBA algorithm. The algorithms were compared using different packet sizes predefined between 10-512 packets per second (packets/sec). The simulation results showed that when the traffic load was low, all 3 algorithms produced similar average packet delivery ratio for both networks with 8 and

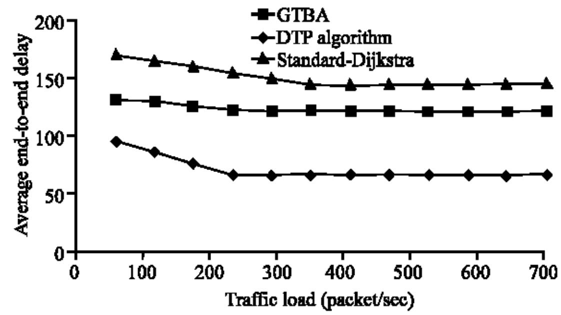

Fig. 6: Average end-to-end delay for 8 nodes with DTP algorithm; end-to-end delay for 8 nodes

15 nodes. When the traffic load increases both standard-Dijstra algorithm and GTBA algorithm produced lower average packet delivery ratio. The proposed DTP algorithm produced higher average packet delivery ratio. The DTP algorithm produced good results, mainly because transferrable payoff coalitional game theory encouraged users to work together and make decisions that benefited all users within a wireless network and a consistent path with the least link load and interference was selected before packet transmission starts (Fig. 4 and 5). In the proposed DTP algorithm, the available bandwidth was allocated based on the traffic type a user wants to send at that particular time. This increased the utilization of the available bandwidth as high-bandwidth traffic had high priority over low-bandwidth traffic.

End-to-end delay: Time taken by a packet in a network to flow from one to another node is known as end-to-end delay. In different kinds of networks delay is a major concern, every network has some kind of delay in it but it is always practiced to reduce the delay in a network as low as possible because it maximizes the network throughput. Delay in a network is a mixture of several kinds of delays which are: D_P, D_T, D_P. Mathematically, it is given by Eq. 6:

$$D_{EZE} = D_P + D_T + D_p \quad (6)$$

Where D_{EZE} is the average end-to-end delay during packet transmission average end-to-end delay for 8 and 15 nodes with DTP algorithm is illustrated in Fig. 6 and 7.

The performance of the algorithms during the simulations was monitored under various packet sizes in a network with 8 and 15 nodes with DTP algorithm. When the traffic load increases the DTP algorithm performed better than both standard-Dijkstra algorithm and GTBA algorithm by reducing end-to-end delay. The proposed

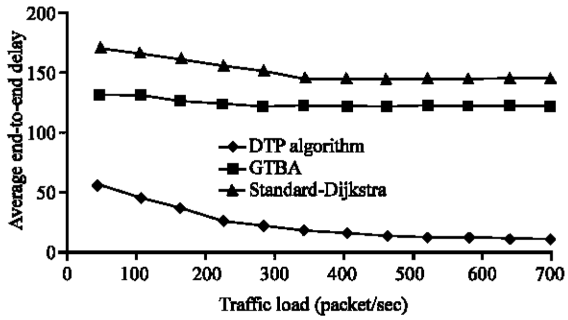

Fig. 7: Average end-to-end delay for 15 nodes with DTP algorithm; end-to-end delay for 15 nodes

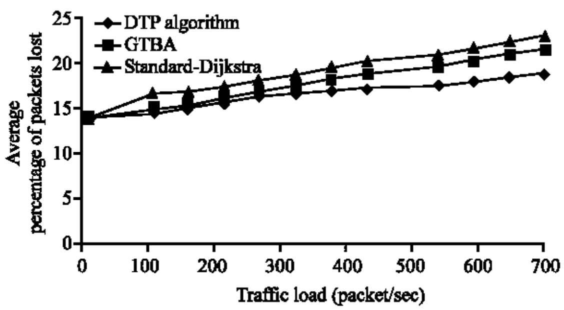

Fig. 8: Average percentage of packets lost for 8 nodes with DTP algorithm; number of packets lost for 8 nodes

DTP algorithm outperformed both standard-Dijkstra algorithm and GTBA algorithm because packets were transmitted over consistent path while high-priority traffic had high priority over low-priority traffic. This integration reduced average end-to-end delay which is a combination of processing delay, transmission delay and propagation delay between communicating users in a wireless network.

Number of packets lost: When a data packet does not reach its destination node from the source node in a communication network, it is called packet loss. Hence, it is important to select a consistent path and when the available bandwidth is properly allocated between communicating users then the best QoS is ensured in a communication network and less chances of packet loss in a network. As indicated by Fig. 8, the packet loss in the proposed DTP algorithm was low as compared to GTBA and standard-Dijkstra. The proposed DTP algorithm produced less number of packet loss, mainy because of a consistent path with least link load and less link interfernce tha was selected (Fig. 8). Additionaly, the available bandwidth was properly allocated between

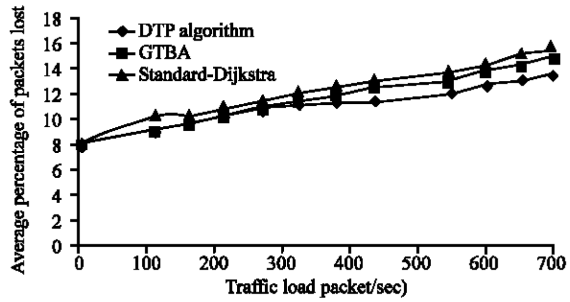

Fig. 9: Average percentage of packets lost 15 nodes with DTP algorithm; number of packets lost for 15 nodes

communicating users whereby high bandwidth traffic was allocated high bandwidth while low bandwidth traffic was allocated low bandwidth in order to reduce the number of packet loss.

The average percentage of packets lost during transmissions which were monitored under various packet sizes using Eq. 7 with 15 nodes with the proposed DTP algorithm is presented in Fig. 9:

$$P_L = \left(\frac{P_T - P_R}{P_T} \right) \times 100 \quad (7)$$

It can be observed from the simulation results that the three algorithms had similar average number of packets lost when the simulations start. When the traffic load increases both standard-Dijkstra algorithm and GTBA algorithm produced high average percentage of packets lost during packet transmission while the DTP algorithm produced lower average percentage of packets lost. In DTP algorithm, transferrable payoff coalitional game was used to allocate high bandwidth to high-priority traffic in order to lessen the number of packets lost for high-priority traffic. As a result, QoS improved because there were less chances of packet loss in a network.

Network throughput: The rate at which the data is transferred from one node to another node in a communication network is the known as throughput (Choi *et al*., 2010). To analyze the network throughput, we used Eq. 8:

$$\text{Through put} = \frac{WS}{RTT} \quad (8)$$

where is the TCP window size while is the round-trip time of communications data packets.

Average network throughput for the three algorithms were monitored and compared under various packet sizes.

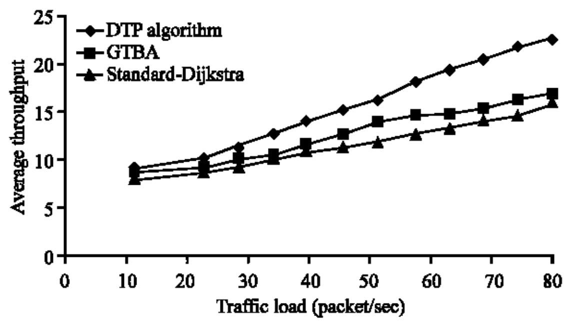

Fig. 10: Average throughput for 8 nodes with DTP algorithm; throughput for 8 nodes

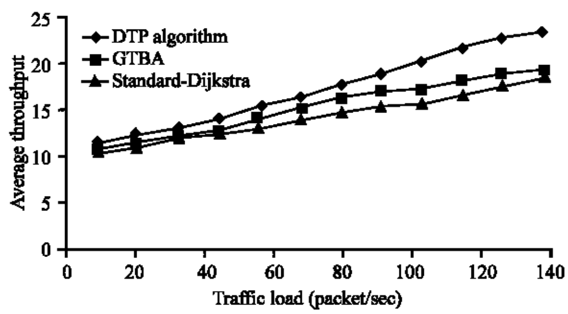

Fig. 11: Average throughput for 15 nodes with DTP algorithm; throughput for 15 nodes

The simulation results showed that the three algorithms produced similar network throughput when the traffic load was very low at 10 packets/sec. The proposed DTP algorithm outperformed both standard-Dijkstra algorithm and GTBA algorithm when the traffic load increases. This was achieved by introducing transferrable payoff coalitional game into hop by hop routing and channel bandwidth selection in the proposed DTP algorithm. The proposed DTP algorithm reduced link congestion and end-to-end delays because high-bandwidth traffic had high priority over low-bandwidth traffic (Fig. 10 and 11). This resulted in high network throughput and better QoS. While in both standard-Dijkstra algorithm and GTBA algorithm, the available bandwidth was just randomly or dynamically allocated between the communicating users.

CONCLUSION

In this study, we presented the design of DTP algorithm by integrating transferrable payoff coalitional game theory and standard-Dijkstra algorithm. The DTTP algorithm reduced link congestion and end-to-end delays that SMEs wireless network systems suffers from. The DTP algorithm uses standard-Dijkstra algorithm to first find a consistent path with low link load and less link interference in order to produce the desired QoS. The proposed DTP algorithm also uses transferrable payoff coalitional game theory to allocate the available bandwidth between communicating users where high-bandwidth traffic had high priority over low-bandwidth traffic. This ensured that high-priority traffic had short delay and this minimized the average percentage of packets lost during packet transmission. In order to validate the performance of the proposed DTP algorithm, simulations were carried out using 8 and 15 nodes with DTP algorithm. The simulation results showed that the proposed DTP algorithm reduced link congestion, end-to-end delay and minimized average percentage of packets lost during transmission. This resulted in improved network throughput and better QoS as compared to standard-Dijkstra algorithm and Game-Theoretic Bandwidth Allocation (GTBA) algorithm.

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