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Improving Throughput in Wireless Data Network Using Cross Layer Alignment Scheme

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Abstract:

This work on Wireless Local Area Network of AFRINET Communications limited, Lagos, Nigeria presents "improving throughput in a wireless data network using cross layer alignment scheme". This was embarked on with the aim of optimizing the throughput response and performance of the case study Wi-fi network structure characterized with poor quality data service and high rate of packet loss. The key performance indicators normally considered in wireless data networks include; Uptime, Network jitter, Bandwidth and Throughput, Signal strength, Packet loss, and Latency. However, particular interest was taken of the NETWORK THROUGHPUT which is the crux of this work. Before the design of the proposed system, the case study network (afri-net communication Nigeria ltd system) was characterized .The result showed that when packet transmitted exceeded 20Mb, the throughput performance became poor. This problem was attributed to improper alignment of the Network layers which we improved upon in this research using cross layer alignment scheme that ensure proper and good alignment of the network layers for maximum communication between them. The model developed was implemented on the modeled Simulink platform. The result shows 91% increase in throughput irrespective of the size of the packet transmitted. Proper alignment of the network layers improves greatly data network transmission.

Keywords — **Throughput, Data Network, Packet, Data Traffic and Transmitted data**

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I. INTRODUCTION

The need to ensure timely and adequate delivery of message and information from source to destination is the motivating factor for this research work. A situation where transmitted data is not fully delivered is not acceptable, even as human life may be dependent on it. Data is life and carries information. Information that is not fully delivered may result in an entire negation of the intended message, hence the need to ensure that the message content is fully and adequately channelled from sender to receiver.

Today networks such as internet, has evolved into a medium of information exchange, ranging from entertainment, commercial enterprises to personal communication in today's communication network efficiency. The benefit of such network only increases due to the advancement in the digital electronic world. Originally, data network delivers data from one network node to another, employing many network methodologies, components such as physical links, internet protocol, transmission control protocols, packet data protocols and computer systems. However, the ever increasing data traffic over wireless network has continuously become a challenging task to mobile communication operator, with the need to deploy sufficient network resources. It is a well-known fact today that the radio spectrum sharing has become a necessity due to the increasing traffic demand and challenges of getting exclusive spectrum. There are however, simple rules for Network operators regarding spectrum sharing which provide a dynamic framework for Spectrum access and sharing of address identified in (Ahokangas et al., 2013).

Data network structures are complex in nature consisting of various entities employed for different network responsibilities like sharing, user mobility and billing. Moreover, a variety of end users have adopted different subscription profiles and applications which bring more challenges for network users and hence make users not very satisfied. To manage this user experience and end system diversity, varieties of information need to be collected from different network layers in a concept based on the cross layer scheme. This project therefore, is designed to introduce proper alignment of the Network layers in a cross layer scheme aimed at improving Throughput delivery in wireless local area data network.

Statement of the problem

It has been observed overtime that incomplete data transmission from source to destination results in a poor communication process. This triggered the need for critical assessment and evaluation of packet delivery and throughput performance, considering the human problem of network losses, congestion and interference within the communication medium.

From the above study, it was observed that various reasons are responsible, but of interest to this research is the inadequate interaction within the network layers of the TCP/IP protocol which is highly responsible for throughput challenges.

To solve the aforementioned problems, it is imperative that the following issues be dealt with having been found to be poor in the conventional system;

- Alignment of the layers
- Network mobility
- Overall quality of service

Failure to solve the above issues will result to common communication problem of inadequate interaction within the protocol layers resulting to the following;

a) Poor throughput performance
b) System exposure to interference and jitters
c) End user dissatisfactions as sender information and messages cannot be adequately and timely delivered to the receivers
d) General poor quality of data communication services, especially at higher data rates.

In the design, each layer is characterized by few key parameters and control knobs. These parameters are passed to other layers to help determine the best adaptation rules for their control knobs. In all, system constraints from various layers are jointly considered for adjusting control knobs in the layers in response to network status changes.

Aim and Objectives of the Study

The aim of this research work is to improve throughput performance in wifi network using cross layer alignment scheme with the following set out objectives;

i. To characterize an existing wireless local area data network (WLAN) throughput performance and develop a model of the characterized system.
ii. To improve on the characterized network through proper alignment of the layers in a cross layer alignment scheme.
iii. To simulate the model as developed above and evaluate the system performance.
iv. To draw conclusions and recommend other ways that wireless data Networks can further be improved.

Significance of the Study

a) Improvement in Network connectivity and Throughput performance.
b) Improved quality of data communication service
c) Fast data delivery service
d) Shield against interference and jitters
e) Minimization of signal losses
f) Adequate and wholesome delivery of data shall also be achieved.
g) Network providers shall fulfill their contractual agreement with their clients as well as save cost.

h) End users, Sender and Receiver, shall be happy that their information and messages are adequately delivered and timely too.

Scope of the Study

This work is limited to improving the performance of wireless local area network only. However the technique can also be employed in WIMAX and other more robust network structures in digital communication industries.

II. MATERIALS AND METHODS

Design Method

The methodology used for this work is simulation through the computer aided software engineering methodology and cross layered scheme for the development of the improved system.
Cross layer alignment scheme refers to sharing information among layers of a communication protocol for efficient use of network resources aimed at achieving high adaptability and performance.
In cross layer design, each layer is characterized by a few key parameters and control knobs. The parameters are passed to other layers to help them determine the best adaptation rules for the control knobs. It is formulated as an optimization problem, with optimization variables and constraints from multiple layers. Solving the optimization problem provides the optimal values for the control knobs in the layers.

3.2 Materials

The materials used for the project basically consisted of data and information collected from the case study Network (AFRINET Communications Ltd). The system set up for the extraction of the key performance indicators by the service provider staff included the use of the following materials:

a) Router
b) Switches
c) Monitoring PC
d) Server
e) Transmitter
f) Receiver
g) RID Net-flow analyzer

CHARACTERIZATION OF WIRELESS NETWORK

This work characterized the AFRINET Communications network Nigeria Ltd, located at Ikeja, Lagos Nigeria with a view to evaluating its quality of service and considering the effect on Throughput performance during end-to-end communication.
The characterization was performed from one end of the network, and monitored rate of Throughput received as data are communicated from one end device to another

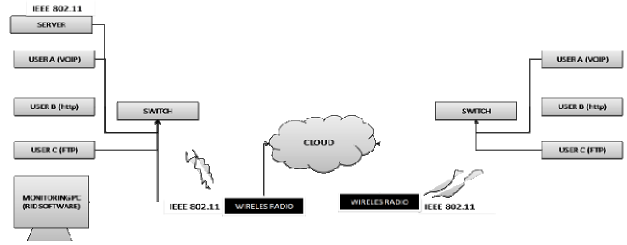

Fig 1 Block diagram of the characterized network

From the network structure of figure 1, each user transmitted and received packet from the other end of the network through the cloud. To perform this characterization, the VOIP Throughput packet transmission performance was monitored during the end to end communication processes using the RID Net-flow software which classifies Throughput based on the ITU – T standard. Results obtained from the characterized network using the Net-flow analyzer is shown in table 1,

Table 1 Results obtained from the characterization of the network of study.

Packet sent (kb)	Throughput (kb)	Throughput (%)	Network performance
10000	9000	90	Throughput Excellent
11000	9500	86	Throughput Very good
12000	10000	83	Throughput Very good
13000	10500	81	Throughput Very good
14000	11000	78	Throughput Good
15000	11200	74	Throughput Good
16000	11200	70	Throughput Good
17000	11300	66	Throughput Good
18000	11500	63	Throughput Good
19000	11700	61	Throughput Good
20000	11800	59	Throughput Fair
22000	11850	54	Throughput Fair

24000	11870	49	Throughput Poor
26000	11930	45	Throughput Poor
28000	11950	39	Throughput Poor
30000	11990	37	Throughput Poor
32000	12150	35	Throughput Poor
34000	12200	33	Throughput Poor
36000	12400	33	Throughput Poor
38000	12430	32	Throughput Poor

Source: Survey from Afrinet, 2020

The results are represented graphically in fig 2 and 3

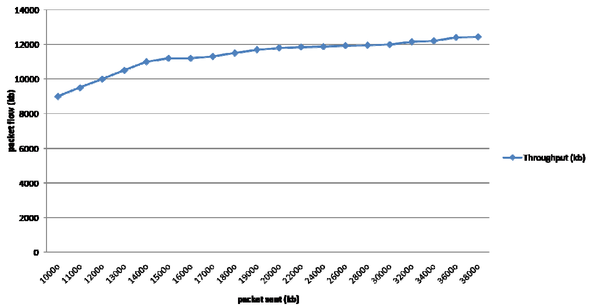

Fig 2: Network performance

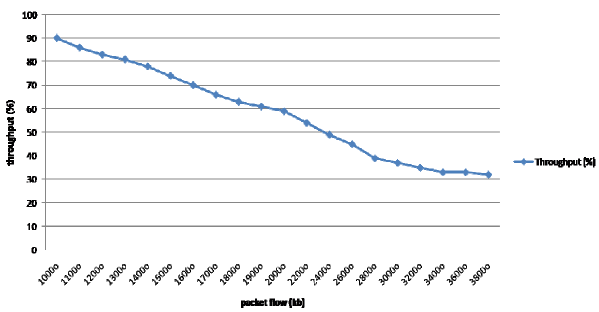

Fig 3: Throughput performance in percentage

From the throughput analyzer result presented in figure 3, it was observed that as the VOIP packet sent increased, the throughput rate decreased. The implication of this result shows that in the network studies, there is need for a network management system which will help optimize throughput performance for higher size of packet sent and hence overall quality of service.

3.4 The improved system

This work proposed the optimization of the throughput performance in wifi network studies using the cross layer scheme. This was achieved using a model of the wifi communication system and then improved using designed cross layer scheme as shown in figure 3.4;

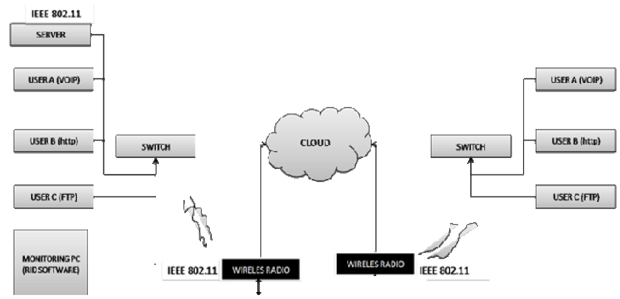

Figure 4: Block diagram of the improved system

The system Design

The system was designed using the following models;

- Model of the wifi network
- Packet flow model
- Cross layer design
- Throughput model

Modelling the Wireless Network

The wifi network model will be developed considering the number of nodes and their distance from each end user based on poison distribution. This model is defined using the relationship between the density λ at the node, which is the network strength at the given time of data transmission , number of nodes n and the distance region B as shown in poison structure equation .1 below, e is the Euler constant, 2.71828;

$$P_{(n)} = \frac{(\lambda\,|B|)^n}{n!} e^{-\lambda\,|B|} \qquad (1)$$

Where B is the distance region, $|B|$ is the area of B,λ is the signal density at the node and $n!$ represent increased user equipment in time series.

Model of the Packet Flow

The model is designed considering two separate parts consisting of the random and deterministic (or non-random) components of signal propagation. The deterministic component is represented by some path-loss function that uses the distance propagated by the signal (from its source) for modeling the power decay of radio VOIP signals. The distance dependent path loss function is a fast decaying exponential function to define the propagation path as shown in equation 2.

$$l\,(|x - y|) = |x-y|^{\alpha} \qquad (2)$$

Where l is signal decay function, |x – y| is distance from source x to point y and α represent the path loss exponent

From the equation, the model is designed using the relationship between the path loss exponent and the VOIP signal decay function. Where the path-loss exponent $\alpha > 2$, and $|x - y|$ denotes the distance between point y and the signal source at point x. the signal decay function is the rate at which the network density reduces over a period of time.

Model of The Cross layer Alignment Scheme

Cross layer scheme refers to sharing information among layers for efficient use of network resources and achieving high adaptability and performance.

In cross layer design, each layer is characterized by a few key parameters and control knobs. These parameters are passed through each layer to help them determine the best adaptation rules for their control knobs. It is formulated as an optimization problem with variables from multiple layers of the proposed scheme solving the problems and providing the necessary optimal values for the control knobs in the layers. The cross layer design employs the five layers of TCP network, providing an inter layer communication relationships, thus enabling information sharing and allowing each layer to determine its behavior based on the packet type (VoIP, Http, Video, etc). This implies that the cross layer scheme enables each layer share status of parameters with the remaining four layers without breaking the structure of the five connected layers. This process ensure the compensation of network performance and reliability through layer boundaries, thus increasing throughput performance, reduced error in bit size, and control traffic. The various methods of cross layer design have been discussed which includes the centralized method and distributive method (see literature review).

This work adopts the distributive method which employs a multi hop path from one node for information sharing in a wifi network as shown below;

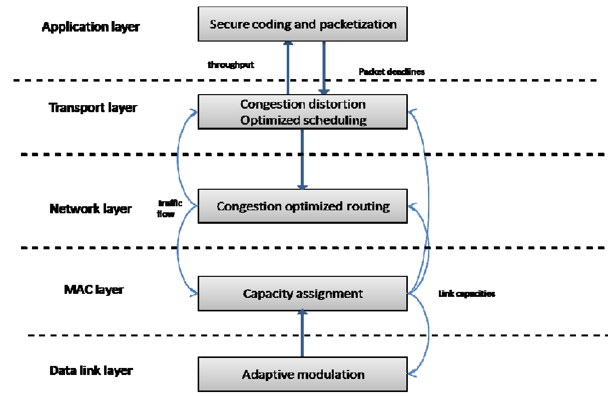

Figure 5: Architecture of the distributive cross layer scheme

From the cross layer architecture, the end to end communication process is improved in the wifi network using a multi-protocol layer which requires upper layers to adapt their varying link strategies and network condition to support daily application constraint like the video streaming, voice over internet protocol, http in wifi ad-hoc network.

Model of Throughput

Throughput is the actual measurement for how fast data can be sent per given time and the variation in the size of throughput shows the rate of congestion within the transmission medium. This section presents the model of the number of bits that are been delivered successfully at the destination end of a communication structure by wifi layer per second. This is related using the structure below in equation 3;

$$Throughput = \frac{\sum_i packet\ size\ (i)}{packet\ arrival\ time\ (n) - packet\ starttime\ (o)} \quad (3)$$

Where packet size is the ith packet at the destination point; the packet start time is the approximate time the packet leaves the transmitter and the packet arrival time is the time when the last packet arrives the destination point.

Implementation of the Cross layer based model

The network was simulated using the parameters in table .2 and the throughput performance was evaluated and presented using the Net-flow analyzer.

Table .2: Simulation parameters

Parameters	**Values**
DNS IP	8.8.8.8
Average noise level	-64 dBm/Hz
The Resolution bandwidth	10 kHz
Middle frequency (f1)	203.25 MHz
Middle frequency (f2)	583.25 MHz
Frequency	224.25 MHz
Power	2.4 kW
Cable Type	RJ45
Impedance	20 ohms
Gateway	172.22.3.1
LAN IP	192.168.10.0/24
WAN IP	172.22.3.99/25
Phase angles	90, 120,180
Modulation and coding	QPSK, 16-QAM
Duplexing scheme	Time division duplexing
Permutation mode	PUSC
Base station antenna height	15m
Transmit power of base station	7W
Carrier frequency	3403, 3408, 3413 MHz

The model is implemented using the necessary mathematical and process models with the designed cross layer scheme which were blended with signal processing toolbox, communication toolbox, optimization toolbox and Simulink to implement the improved cross layer based wifi network as shown in the structure below (see source code in appendix A);

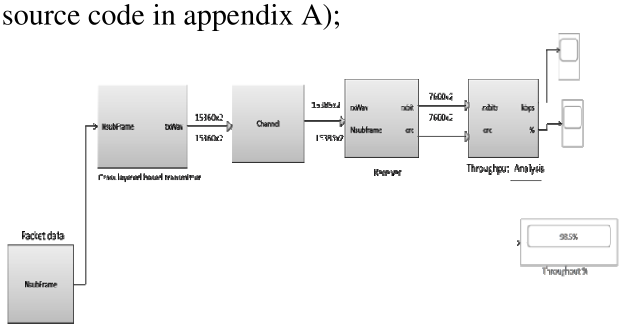

Figure 6: model of the improvedwifi network

From the Simulink model in figure 3.6, the improved wifi network was presented using the wifi network model in equation 1 which is a poison structure to transmit VOIP packet using the packet flow model in equation 2 to the end user. The quality of this packet flow transmitted was improved using the cross layer scheme proposed and integrated in the network using the design in figure 5; the essence is to ensure adaptive equalization of the signal before they get to the receiver end to guarantee quality of service delivery with perfect throughput performance. To confirm this effect, the network was simulated and the results shall be presented in the next chapter.

III. RESULTS AND DISCUSSION

Results

This chapter presents the simulation performance and results of the cross layer improved network structure. The cross layer scheme consists of five layers which start with the application layer that ensured the packetization of the transmitted data according to specific protocols to the other four layers for optimization. When this is done, the transport and network layers control congestion of the signal by avoiding packet interference from other incoming signal. The media access control layer and data link layer on the other hand ensured adaptive modulation of the packet to collectively guarantee quality of throughput which is 91% as shown below using the throughput model in equation 3. The size of this packet transmitted in kilobit is also analyzed and presented as shown below;

From the simulation of the improved network structure the throughput performance of the VOIP transmitted was monitored and the result is shown in Fig 7 below.

Similarly, from the result of the simulation it was observed that total out of the 12000kb of VOIP packet sent, 10920kb was received which is equivalent to 91% throughput as indicated in the graph in figure 7. The implication of this result shows that the cross layer scheme has optimized the throughput performance of the network to 91% improved quality of service.

Table 3: Result of the new system with VoIP data

Packet sent (kb)	**Throughput (kb)**	**Throughput (%)**	**Network performance**
10000	9100	91	Throughput excellent
11000	10010	91	Throughput excellent
12000	10920	91	Throughput excellent
13000	11830	91	Throughput excellent
14000	12740	91	Throughput excellent

15000	13650	91	Throughput excellent
16000	14560	91	Throughput excellent
17000	15470	91	Throughput excellent
18000	16380	91	Throughput excellent
19000	17290	91	Throughput excellent
20000	18200	91	Throughput excellent
22000	20020	91	Throughput excellent
24000	21840	91	Throughput excellent
26000	23660	91	Throughput excellent
28000	25480	91	Throughput excellent
30000	27300	91	Throughput excellent
32000	29120	91	Throughput excellent
34000	30940	91	Throughput excellent
36000	32760	91	Throughput excellent
38000	34580	91	Throughput excellent

Source: Researcher's computation

From the result reported in the table 4, the throughput performance of the network on VOIP data is recorded and presented graphically in figure 3.It was also observed that the network performance according to the Net-flow rating is excellent with a constant throughput rate of 91% despite the increase in packet transmitted.

The overall network performance is further analyzed given the graph shown in figure 8;

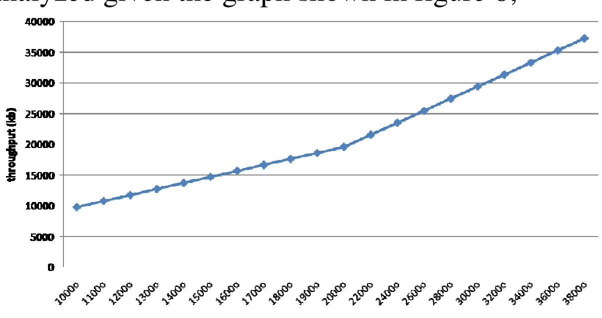

Figure 7: improved throughput performance on Afrinet.

From the network result in figure 7, it was observed that the throughput performance is directly proportional to the packet sent. The implication of this result shows that an excellent improvement have been achieved on the Afri-net quality of service.

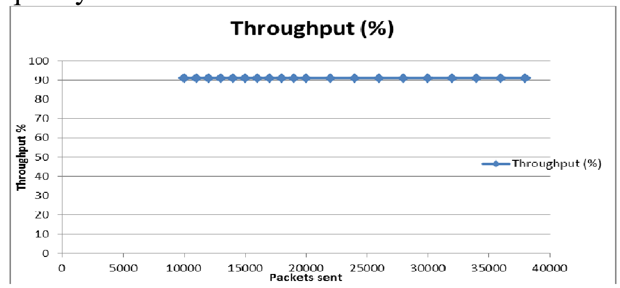

Figure 8: result of the Network performance (%)

Validation of the study

To validate this research a comparative analysis was performed on the new system and the characterized network and the result is presented as shown in Table 4;

Table 4: comparative analysis

Packet sent (kb)	Through put (kb)	Through put (%)	Throughp ut (kb)	Throug hput (%)
	Cross layer scheme		Characterized	
10000	9100	91	9000	90
11000	10010	91	9500	86
12000	10920	91	10000	83
13000	11830	91	10500	81
14000	12740	91	11000	78
15000	13650	91	11200	74
16000	14560	91	11200	70
17000	15470	91	11300	66
18000	16380	91	11500	63
19000	17290	91	11700	61
20000	18200	91	11800	59
22000	20020	91	11850	54
24000	21840	91	11870	49
26000	23660	91	11930	45
28000	25480	91	11950	39
30000	27300	91	11990	37
32000	29120	91	12150	35
34000	30940	91	12200	33
36000	32760	91	12400	33
38000	34580	91	12430	32

Source: Researcher's computation

From the result reported in table 4, a comparative cross layered improved network and the characterized network was presented showing their respective throughput performance as packet is transmitted incrementally. This result is analyzed for throughput performance and rate as shown respectively using figure 4 and 5;

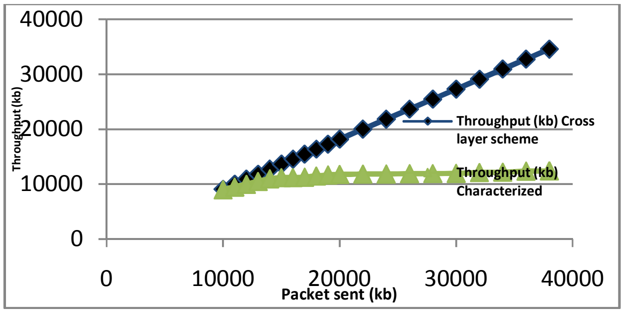

Figure 9: Comparative throughput performance

From the result in figure 9, it was observed that the throughput for the characterized network was fairly constant as the packet increased, but when the network was improved with cross layered scheme, the throughput become proportional to the packet transmitted. This implies that the network quality for the new system is excellent. The comparative throughput rate is analyzed and presented below;

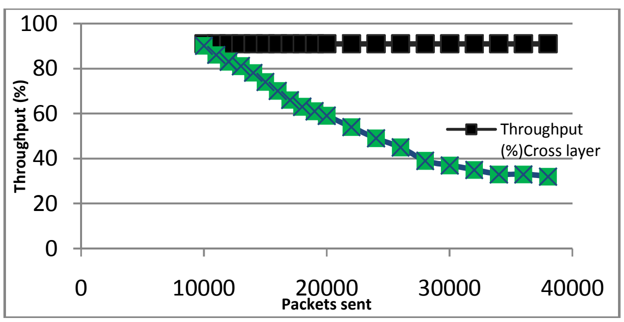

Figure 10: comparative throughout rate

The comparative throughput rate for the new and characterized system presented in figure 10 shows that the new system have a constant throughput even as the packet transmitted increased, while the characterized network have a reduced throughput performance and become very poor as the packet transmitted exceeds 20000kb.

IV. CONCLUSION AND RECOMMENDATIONS

Summary of Findings

Improving throughput performance over the years has been a major challenge begging to be rectified in wireless communication systems. Many works have been proposed and published, all suggesting various hypothetical approaches to help combat the inevitable problems affecting wireless communication like latency, poor signal quality, noise, packet loss among other. However recently researchers have focused more attention on the cross layer scheme to help solve this problem due to the huge benefits it offers like improved throughput, limited packet loss, better quality of service, congestion control, security and mobility. The cross layer design employs the five layers of TCP network, providing an inter layer communication relationships, thus enabling information sharing and allowing each layer to determine its behavior. This work adopted the cross layer technique to improve the Afrinet communication system characterized with poor quality of service, high packet loss rate, Noise, and delay in transmission time of packet. Improvement was achieved through the proper and adequate alignment of the layers, in other to ensure proper communication between layers.

Conclusion

This work has successfully, developed and implemented an improved wireless data network using cross layer alignment scheme. The work was done using cross layer scheme to improve the rate of throughput and minimize packet loss among other advantages like improved security feature, mobility feature and quality of service. This was achieved using the necessary mathematical models to design the proposed system and implemented with simulink. Before the design of the proposed system, the Afrinet communication system was characterized and the result recorded showed that the network was poor when packet over 20000kb was transmitted. However this was improved ensuring constant throughput rate of 91% irrespective of the packet size sent.

Contribution to knowledge

This project work has shown that proper alignment of the network layers in a Cross layer scheme of wireless data network can be used to improve Throughput delivery. It has shown great improvement on the throughput of the system from 58.4% to 91% delivery rate.

Recommendation

Having completed this project work, I recommend for further study; a hybrid technique that can be combined with this cross layer alignment scheme to improve speed of transmission and quality of service as well.

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APPENDIX A (SOURCE CODES)

```
Set simulation parameters
runDuration = 10;        % Seconds
numPayloadBits = 19530;   % Bits
packetArrivalRate = 0.2;  % Packets per second
ackTimeOut = 0.25;       % ACK time out in seconds
maxBackoffTime = 10;       % Maximum time in packTimeOut durations
mMaxDataRetries = 5;     % Maximum DATA retries
queueSize = 10;          % Data Link Layer queue size in packets
samplesPerFrame = 2000;   % Number of samples processed every iteration
verbose = true;          % Print packet activity to command line
sampleRate = 200e3;
% Create packetized modem nodes
node1 = helperPacketizedModemNode(...
  'Address', 1, ...
  'DestinationList', [2, 3], ...
  'NumPayloadBits', numPayloadBits, ...
  'PacketArrivalRate', packetArrivalRate, ...
  'ACKTimeOut', ackTimeOut, ...
  'MaxBackoffTime', maxBackoffTime, ...
  'MaxDataRetries', mMaxDataRetries, ...
  'QueueSize', queueSize, ...
  'CarrierDetectorThreshold', 1e-5, ...
  'AGCMaxPowerGain', 65, ...
  'SamplesPerFrame', samplesPerFrame, ...
  'Verbose', verbose, ...
  'SampleRate', sampleRate);
node2 = helperPacketizedModemNode(...
  'Address', 2, ...
  'DestinationList', [1 3], ...
  'NumPayloadBits', numPayloadBits, ...
  'PacketArrivalRate', packetArrivalRate, ...
  'ACKTimeOut', ackTimeOut, ...
  'MaxBackoffTime', maxBackoffTime, ...
  'MaxDataRetries', mMaxDataRetries, ...
  'QueueSize', queueSize, ...
  'CarrierDetectorThreshold', 1e-5, ...
  'AGCMaxPowerGain', 65, ...
  'SamplesPerFrame', samplesPerFrame, ...
  'Verbose', verbose, ...
  'SampleRate', sampleRate);
node3 = helperPacketizedModemNode(...
  'Address', 3, ...
  'DestinationList', [1 2], ...
  'NumPayloadBits', numPayloadBits, ...
  'PacketArrivalRate', packetArrivalRate, ...
  'ACKTimeOut', ackTimeOut, ...
  'MaxBackoffTime', maxBackoffTime, ...
  'MaxDataRetries', mMaxDataRetries, ...
  'QueueSize', queueSize, ...
  'CarrierDetectorThreshold', 1e-5, ...
  'AGCMaxPowerGain', 65, ...
  'SamplesPerFrame', samplesPerFrame, ...
  'Verbose', verbose, ...
  'SampleRate', sampleRate);

% Setup channel
channel = helperMultiUserChannel(...
  'NumNodes', 3, ...
  'EnableTimingSkew', true, ...
  'DelayType', 'Triangle', ...
  'TimingError', 20, ...
  'EnableFrequencyOffset', true, ...
            'PhaseOffset', 47, ...
  'FrequencyOffset', 2000, ...
  'EnableAWGN', true, ...
  'EbNo', 25, ...
  'BitsPerSymbol', 2, ...
  'SamplesPerSymbol', 4, ...
  'EnableRicianMultipath', true, ...
  'PathDelays', [0 node1.SamplesPerSymbol/node1.SampleRate], ...
  'AveragePathGains', [15 0], ...
  'KFactor', 15, ...
            'MaximumDopplerShift', 10, ...
  'SampleRate', node1.SampleRate);

% Main loop
radioTime = 0;
nodeInfo = info(node1);
frameDuration = node1.SamplesPerFrame/node1.SampleRate;
[rcvd1,rcvd2,rcvd3] = deal(complex(zeros(node1.SamplesPerFrame,1)));
whileradioTime<runDuration
  trans1 = node1(rcvd1, radioTime);
  trans2 = node2(rcvd2, radioTime);
  trans3 = node3(rcvd3, radioTime);

  % Multi-user channel
  [rcvd1,rcvd2,rcvd3] = channel(trans1,trans2,trans3);

% Update radio time.
radioTime = radioTime + frameDuration;
end

% Create a format configuration object for a SISO VHT transmission
cfgVHT = wlanVHTConfig;
cfgVHT.NumTransmitAntennas = 1;    % Transmit antennas
cfgVHT.NumSpaceTimeStreams = 1;    % Space-time streams
cfgVHT.APEPLength = 4096;          % APEP length in bytes
cfgVHT.MCSCrosslayer = 5;                 % Single spatial stream, 64-QAM
cfgVHT.ChannelBandwidth = 'CBW20'; % Transmitted signal bandwidth
Rs = wlanSampleRate(cfgVHT);       % Sampling rate

% generates the L-STF field in the time-domain using some of the parameters
% included in configuration object |cfgVHT|.
Crosslayerlstf = wlanLSTF(cfgVHT);
%%
% The L-LTF is used for fine time synchronization, channel estimation and
% fine frequency offset estimation. The <matlab:doc('wlanLLTF') wlanLLTF>
% function generates the L-LTF in the time-domain.
Crosslayerlltf = wlanLLTF(cfgVHT);
%%
% The L-SIG field carries packet configuration such as data rate,
% modulation and code rate for non-HT format. The <matlab:doc('wlanLSIG')
% wlanLSIG> function generates the L-SIG field in the time-domain.
lsig = wlanLSIG(cfgVHT);
%%
% The figure below shows the L-STF, L-LTF and L-SIG fields. These fields
% are common to the VHT, HT-Mixed and non-HT OFDM transmission formats.
nonHTfieldCrosslayer = [lstf;lltf;lsig]; % Combine the non-HT preamble fields
% field in the time-domain.
vhtsiga = wlanVHTSIGA(cfgVHT);
% function generates the VHT-STF field in the time-domain.
```



```
vhtstf = wlanVHTSTF(cfgVHT);
% the time-domain.
vhtltf = wlanVHTLTF(cfgVHT);
%%
% field in the time-domain.
VhtsigbCrosslayer = wlanVHTSIGB(cfgVHT);
%%
% Construct the preamble with the generated signal and training
fields for
% the VHT format.
preamble = [lstf;lltf;lsig;vhtsiga;vhtstf;vhtltf;vhtsigb];

%%

rng(0) % Initialize the random number generator
txPSDU = randi([0 1],cfgVHT.PSDULength*8,1); % Generate
PSDU data in bits
data = wlanVHTData(txPSDU,cfgVHT);

% A VHT waveform is constructed by prepending the non-HT and
VHT
% preamble fields with data
txWaveformCrosslayer = [preamble;data]; % Transmit VHT PPDU

the help for <matlab:doc('wlanTGacChannel')
% wlanTGacChannel>.

% Parameterize the channel
tgacChannel = wlanTGacChannel;
tgacChannel.DelayProfile = 'Model-B';
tgacChannel.NumTransmitAntennas =
cfgVHT.NumTransmitAntennas;
tgacChannel.NumReceiveAntennas = 1;
tgacChannel.LargeScaleFadingEffect = 'None';
tgacChannel.ChannelBandwidth = 'CBW20';
tgacChannel.TransmitReceiveDistance = 5;
tgacChannel.SampleRate = Rs;
tgacChannel.RandomStream = 'mt19937ar with seed';
tgacChannel.Seed = 10;

% Pass signal through the channel. Append zeroes to compensate
for channel
% filter delay
txWaveform = [txWaveform;zeros(10,1)];
chanOut = tgacChannel(txWaveform);

snr = 40; % In dBs
rxWaveform = awgn(chanOut,snr,0);

% Display the spectrum of the transmitted and received signals.
The
% received signal spectrum is affected by the channel
spectrumAnalyzer =dsp.SpectrumAnalyzer('SampleRate',Rs, ...
    'ShowLegend',true, ...
    'Window', 'Rectangular', ...
    'SpectralAverages',10, ...
    'YLimits',[-30 10], ...
    'ChannelNames',{'Transmitted waveform','Received
waveform'});
spectrumAnalyzer([txWaveformrxWaveform]);

%%

chInfo = info(tgacChannel); % Get characteristic information
% Channel filter delay, measured in samples
chDelay =chInfo.ChannelFilterDelay;
rxWaveform = rxWaveform(chDelay+1:end,:);

%%
indField = wlanFieldIndices(cfgVHT);

%%
indLLTF = indField.LLTF(1):indField.LLTF(2);
demodLLTF =
wlanLLTFDemodulate(rxWaveform(indLLTF),cfgVHT);
% Estimate noise power in VHT fields
nVar =
helperNoiseEstimate(demodLLTF,cfgVHT.ChannelBandwidth, ...
cfgVHT.NumSpaceTimeStreams);

%%
% To extract the VHT-LTF from the received signal the start and
end indices
% are used to generate a vector of indices.
indVHTLTF = indField.VHTLTF(1):indField.VHTLTF(2);

% wlanVHTLTFDemodulate> function.
demodVHTLTF =
wlanVHTLTFDemodulate(rxWaveform(indVHTLTF,:),cfgVHT);

% receive antennas.
chanEstVHTLTF =
wlanVHTLTFChannelEstimate(demodVHTLTF,cfgVHT);

%%
% The transmit signal encounters a deep fade as shown in the
channel
% frequency response in the figure below. The effect of channel
fades can
% also be seen in the spectrum plot shown previously.
figure
plot(20*log10(abs(chanEstVHTLTF)));
grid on;
title('Estimated Channel Response');
xlabel('Subcarrier index');
ylabel('Power (dB)');

%%
% To extract the data field from the received signal the start and
end
% indices for the data field are used to generate a vector of indices.
indData = indField.VHTData(1):indField.VHTData(2);

% Recover the bits and equalized symbols in the VHT Data field
using the
% channel estimates from VHT-LTF
[rxPSDU,~,eqSym] =
wlanVHTDataRecover(rxWaveform(indData,:), ...
chanEstVHTLTF,nVar,cfgVHT);

% Compare transmit and receive PSDU bits
numErr = biterr(txPSDU,rxPSDU);

%%
% The following plot shows the constellation of the equalized
symbols at
% the output of the <matlab:doc('wlanVHTDataRecover')
wlanVHTDataRecover>
% function compared against the reference constellation.
Increasing the
% channel noise should begin to spread the distinct constellation
points.

% Plot equalized symbols
constellationDiagram = comm.ConstellationDiagram;
constellationDiagram.ReferenceConstellation= ...
helperReferenceSymbols(cfgVHT);
% Compare received and reference constellation
constellationDiagram(reshape(eqSym,[],1));
constellationDiagram.Title = Crosslayer 5:4:3:2:1
end
```