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Multiple Users Round Trip Time Models in IEEE 802.11b WLANS

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ABSTRACT: The dependence of Round Trip Time (RTT) on Signal to Noise Ratio (SNR) for multiple users in an IEEE 802.11b Wireless Local Area Network (WLAN) was studied in this work. Data collected in open corridor, small offices and free space environments in an infrastructure based network (where different quality of service traffic were continuously being sent by multiple users) was used to develop and validate Multiple User RTT models predicted from computed SNR.The models were also compared with single user models earlier developed. The tests results show that for multiple users on the network, RTT can be predicted from the computed SNR with reasonable accuracy as the models passed the F and T test at 0.1% level of significance and RMS errors of less than 867.378214ms were observed. During network design and installation, these models provide useful tools that can enable IEEE 802.11b WLAN installers to make fast and better informed RTT decisions.

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WLANs are at the fore front in providing convenient access to the internet within organizations (Oghogho and Ezomo, 2013). Research has shown that throughput and RTT are the two most important metrics for determining WLANs performance (Geier, 2008a). A minimum throughput and a maximum RTT is necessary and must be satisfied by a network to ensure acceptable performance (Geier, 2008b). RTT has been defined as the time required for a signal pulse or packet to travel from a specific source to a specific destination and back again (Ali and Khuder; 2012). RTT depend on the throughput of the source connection and several other factors namely (El Miloud *et al.*, 2013): (i) the nature of the transmission medium (ii) the physical distance between the source and the destination. (iii) the number of nodes between the source and the destination. (iv) the amount of traffic on the LAN (local area network) to which the end user is connected. (v) the number of other requests being handled by intermediate nodes and the remote server. (vi) the speed with which intermediate nodes and the remote server function. (vii) the presence of interference in the circuit. Most of these factors on which RTT depend (like the throughput of the source connection and factors (ii), (vi) and (vii) as listed above) are also directly related to the SNR present (Oghogho, 2018; Geier, 2008a; Geier, 2008b; Domenico and Stefan, 2011). Throughput in WLANs has been predicted directly from the computed SNR by Henty, (2001); Oghogho *et al.*,(2014a), Oghogho *et al.*, (2014b) Oghogho *et al.*,(2015a), Oghogho *et al.*,(2015b), Oghogho, (2017), Oghogho *et al.*, (2017), Oghogho *et al.*,(2018). Just as is the case for the throughput, several work including Li *et al.*, (2009), El Miloud *et al.,* (2013), Zobenko *et al.*, (2014), Stephen, (2013), Nafei *et al.*, (2013), Domenico and Stefan, (2011), Kavidha and Sadasivam (2010) exist that also studied and predicted the RTT. However, these researches do not directly model RTT from the observed SNR only. Oghogho (2018) showed that since RTT depends on several factors which are themselves directly dependent on the measured received signal strength indication from which SNR is computed, RTT can be modelled directly from the computed SNR for a single user on an IEEE802.11b WLAN. However no such work has been done for multiple users on the network. This paper seeks to fill this gap.

MATERIALS AND METHODS

The methods used in Oghogho, *et al.,* (2014a) and Oghogho, (2018) were also used in this work except that multiple users RTT data was collected instead of Throughput data as done in Oghogho *et al.,* (2014a). Also multiple users RTT data was collected instead of single user RTT data as done in Oghogho, (2018). The number of users was chosen as seven due to the work of Wu *et al.,*(2011) where seven users

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represented saturation traffic where each client always has a packet to send. Multiple Users RTT models predicted from SNR were statistically developed and compared with validation data for: (i) All signals considered, (ii) Strong signals (SNR>25dB) only, (iii) Grey signals (25dB>SNR>18dB) only (iv) Weak signals (SNR<19dB) only. The multiple users models developed were also compared with single user models earlier developed and their performances were tested by computing the RMS errors,"F" and "t" tests.

RESULTS AND DISCUSSION

Multiple Users RTT field and validation data statistical parameters are shown in Table 1 for different SNR categories. In Fig. 1, averages and standard deviation of multiple users RTT field data have been plotted against SNR. From Table 1, it can be observed that the standard deviation is high even when signal was strong implying that RTT varies considerably for multiple users on the network. This is a deviation from what was observed for single user on the network as reported by Oghogho (2018) where the observed RTT standard deviation was low.The increase in standard deviation at the boundary (SNR=25dB) between strong and grey signals can be noticed on Figure 1. For the RTT multiple users data statistics presented in this work, greater means, standard deviations and variances for RTT were observed for all signal ranges compared with single user data statistics presented by Oghogho (2018).

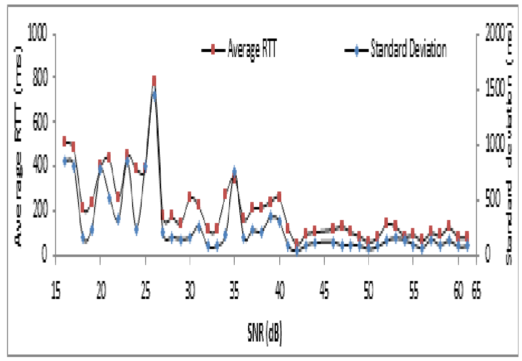

Fig. 1: Averages and Standard deviation of Multiple Users RTT field data Vs SNR.

Table 1: Statistical Parameter Values of RTT data for Different Cases of Received SNR.

Statistical Parameter	**ALL RSSI (SNR) considered (63dB≥ $SNR \geq 13dB$)**		**Strong Signal (SNR ≥ 25dB)**	
	RTT Field data	**RTT Validation data**	**RTT Field data**	**RTT Validation data**
N (Sample Size)	1844	524	1451	419
Mean	191.96329	173.2341	148.437147	181.7918
Std. Error of Mean	9.405635	18.03244	8.4579804	21.33340
Median	93	40.5500	78.9	43.8000
Mode	2.9	1.90	2.9	1.90
Std. Deviation	403.8951	412.78149	322.1813368	436.68374
Variance	163131.2	170388.559	103800.814	190692.691
Coefficient of dispersion	2.1040226	2.3827958	2.17048996	2.4021091
Skewness	7.442	5.589	10.331	5.592
Std. Error of Skewness	0.057	0.107	0.064	0.119
Kurtosis	72.012	39.193	135.857	37.950
Std. Error of Kurtosis	0.114	0.213	0.128	0.238
Range	5483.5	4161.80	5483.5	4161.80
Statistical Parameter	**Grey signal (25dB>SNR≥19dB)**		**Weak Signal (SNR < 19dB)**	
	RTT Field data	**RTT Validation data**	**RTT Field data**	**RTT Validation data**
N (Sample Size)	362	39	32	66
Mean	351.6677	183.4128	459.9094	112.8909
Std. Error of Mean	30.82918	64.58314	143.8395	26.21066
Median	177.2	23.8000	223.3	20.1500
Mode	7.1	3.50*, 7.5*	89.3	5.00*, 6.2*
Std. Deviation	586.56516	403.32160	813.6792	212.93640
Variance	344058.683	162668.316	662073.8	45341.909
Coefficient of dispersion	1.6681987	2.1988928	1.769216	1.886214
Skewness	4.497	2.878	2.857	4.227
Std. Error of Skewness	0.128	0.378	0.414	0.295
Kurtosis	27.134	8.611	7.299	22.616
Std. Error of Kurtosis	0.256	0.741	0.809	0.582
Range	5038.40	1889.10	3161.8	1419.40

Multiple mode exist

This implies that packet queuing and delays in packet transmission increase with increase in the number of users on the network. This results because the network traffic is congested by the many users all having a packet to send. This congestion leads to the selection of lower transmission rates by the error control mechanism which aims to reduce errors in packet transmission thus leading to longer round trip times of packets.

Development of RTT Models: Parameters of Multiple users RTT models developed using Statistical packages for Social sciences (SPSS) are shown in Table 2. RTT (ms) is predicted directly from the observed SNR (dB). The four models (i) RTT General Multiple Users model (RTTGMUM), (ii) RTT Strong Signal Multiple Users Model, (RTTSSMUM) (iii) RTT Grey Signal Multiple Users Model (RTTGSMUM)and (iv) RTT Weak Signal Multiple Users Model (RTTWSMUM) are presented in equation 1-4 respectively. The model coefficient (a_1) has different values for each model.

Table 2: Developed Models Parameters

S/N	Model Name	Model Description	Sample Size	R^2 value	Standard error of estimate	Level of significance
1	RTTGMUM	Power Model	1813	0.853	1.733	0.000%
2	RTTSSMUM	Power Model	1447	0.867	1.583	0.000%
3	RTTGSMUM	Power Model	334	0.920	1.466	0.000%
4	RTTWSMUM	S-Curve Model	32	0.953	1,215	0.000%

RTTGMUM $= f(SNR) = SNR^{a_1}$……………..1

RTTSSMUM $= f(SNR) = SNR^{a_1}$....................2

RTTGSMUM $= f(SNR) = SNR^{a_1}$....................3

RTTWSMUM $= f(SNR) = e^{(a_1/_{SNR})}$...............4

Tests and Discussion: To test the models, the **Null hypothesis 1; (H_0)** was defined to mean RTT does not depend significantly on SNR when there are multiple Users on the network. **Alternative hypothesis 1; H_I** was defined to mean RTT depends significantly on SNR when there are multiple Users on the network. Table 3 shows the root means square (RMS) errors, the F-distribution and T test results. H_0 was rejected for all cases and all the models were accepted at 1% level of significance at the respective degrees of freedom. This implies that for multiple users on the IEEE 802.11b WLAN, RTT significantly depends on SNR computed and the models developed can predict RTT from computed SNR within reasonable accuracy. Table 4 shows comparison of the multiple users RTT models developed in this work with the similar single user RTT models developed by Oghogho (2018).

Table 3: Computed RMS Errors, F and T Tests Results

Model type	**RMS error value (ms)**		**F test**		**T Test**		**Decision**
			F value from Model	**F value from Table**	**T value from Model**	**T value from Table**	
RTTGMUM	All SNR	186.604172	$F_{0.01,1,1812}$ = 10531.945	6.63	70.295	$T_{0.005,1884}$ = 2.58	H_0 is rejected. Model is accepted at 1% level of Significance
	Limited to Strong Signals only	186.1866975					
	Limited to Grey Signals only	247.809					
	Limited to Weak Signals only	113.96176					
RTTSSMUM	198.5662945		$F_{0.01,1,1446}$ = 9405.073	6.63	96.689	$T_{0.005,1502}$ = 2.58	H_0 is rejected. Model is accepted at 1% level of Significance
RTTGSMUM	176.4396		$F_{0.01,1,333}$ = 3807.053	6.63	26.861	$T_{0.005,315}$ = 2.58	H_0 is rejected. Model is accepted at 1% level of Significance
RTTWSMUM	867.378214		$F_{0.01,1,31}$ = 633.849	7.56	14.624	$T_{0.005,62}$ = 2.62	H_0 is rejected. Model is accepted at 1% level of Significance

From Table 4, it can be seen that the RTTGMUM performed better than all others as it showed lower RMS errors in the different cases considered except for the grey signals where the RTTGSMUM (RMS error =176.4396) performed better than the RTTGMUM (RMS error =247.809). Also, all the Multiple users models developed in this work showed lower RMS errors compared with single user models developed by Oghogho 2018. However when the signal becomes weak, the multiple user models (developed from the weak signals field data) showed a very high RMS error (867.378214) compared with the RMS error (124.5541) of the corresponding single user models developed by Oghogho (2018).

Table 4: Comparison of developed Multiple Users Models with Previous Single User Models

Multiple Users Model type	RMS error value (ms)		Single User Model type	RMS error value (ms)	
RTTGMUM	All SNR	186.604172	Oghogho 2018 Single User General Model	All SNR	230.1767181
	limited to Strong Signals only	186.1866975		limited to Strong Signals only	237.3566248
	Limited to Grey Signals only	247.809		Limited to Grey Signals only	269.8166006
	Limited to Weak Signals only	113.96176		Limited to Weak Signals only	123.9854968
RTTSSMUM	198.5662945		Oghogho 2018 Single User Strong Signal Model	237.3443	
RTTGSMUM	176.4396		Oghogho 2018 Single User Grey Signal Model	269.7291	
RTTWSMUM	867.378214		Oghogho 2018 Single User Weak Signal Model	124.5541	

This happened because for multiple users, when signal has become weak the variability of RTT becomes very high as seen in the high standard deviation (813.6792ms) computed from the weak signal RTT field data statistics in Table 1. Thus for weak signals, the general model (RTTGMUM) should be used for RTT prediction. Figure 2 shows the plot of RTT validation data along with the General RTT multiple users model (RTTGMUM) and Oghogho 2018 Single User General RTT model. The graph shows clearly that the RTTGMUM developed in this work follows the validation data more closely. This was already proven from the computed RMS error in Table4. Figure 3-5 shows plots of RTT validation data along with the developed models for strong, grey and weak signals respectively.

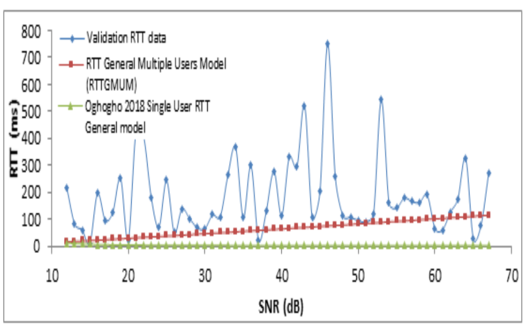

Fig. 2: Comparison of RTT Models for all SNR Considered

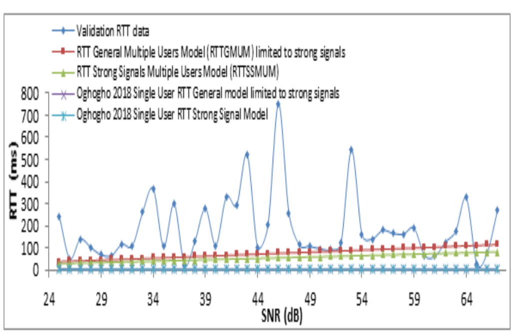

Fig.3: RTT Models in the Strong Signal Range only

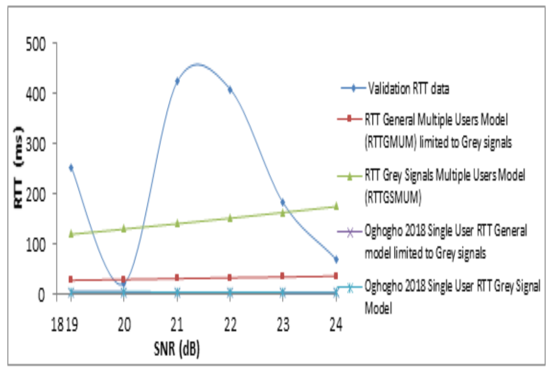

Fig.4: RTT Models in the Grey Signal Range only

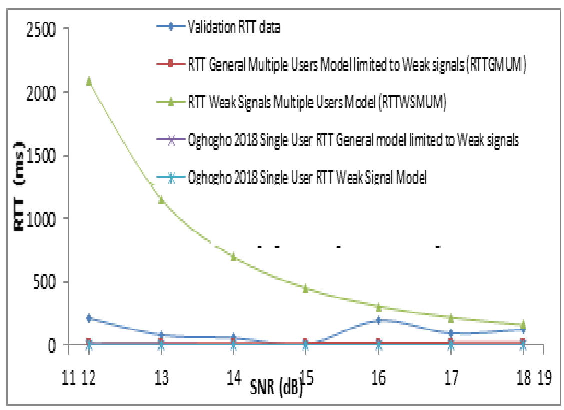

Fig.5: RTT Models in the Weak Signal Range only

From the various graphs of Figure 2-5 and Table 4 which compared the performances of the models using RMS errors, it can be seen that proceeding to develop models to predict RTT for multiple users in an IEEE 802.11b WLAN was necessary as the multiple users models performed better by showing lower RMS errors compared with that of the single user models earlier developed.

Conclusion: RTT multiple users models that can predict RTT based on the computed SNR only for various signal ranges in IEEE 802.11b WLANs have been developed, validated, tested for performance and compared with similar single user models earlier developed. By showing low RMS errors and having passed the F and T tests, the developed models can be relied upon to provide prediction of the RTT in IEEE 802.11b WLANs based on SNR observed.

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