Environment Specific TCP Upstream Throughput Models in IEEE802.11b WLAN.

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ABSTRACT: This paper presents our study on environment based dependence of TCP Upstream Throughput (TCP_{u,T}) on signal to noise ratio (SNR) for a single user in an IEEE 802.11b Wireless Local Area Network (WLAN). Small offices, open corridors and free space environments were studied using an infrastructure based network for different quality of service (QoS) traffic. Environment based Models that predict TCP_{u,T} directly from SNR for different signal categories were statistically generated, validated and compared with similar models that were earlier developed without considering specific environments. The first type of models developed in this work were developed from all data specifically collected from each environment while the second type of models were developed by first categorizing the data in each specific environment into different signal categories and then models were statistically generated for each signal category before combining them into one model equation. At the stated levels of significance and the different degrees of freedom, the developed models were accepted at 1% (for F test) and 0.5% (for T test). From the RMS errors computed, the specific environment based models developed in this work were more accurate (as they showed lower RMS errors compared with earlier similar models) in predicting TCP_{u,T} in IEEE 802.11b WLAN for a single user on the network. It was also observed that the second type of models were found to be more accurate having shown lower RMS errors.

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The internet has become an integral part of our everyday life (Mohammed, 2011). Smart phones, computers and other internet enabled devices can now use Wireless local area networks (WLANs) to access internet services in many homes and within organizations. This has made access to information easier and more efficient (Oghogho and Ezomo,2013). Throughput and the round trip time are the two most important metrics for determining the performance of WLANs (Geier, 2008a). Being able to predict and simulate the throughput in WLANs can help to determine the performance of such a network. A minimum throughput must be provided by a WLAN if it is to be considered to have provided sufficient coverage (Geier, 2008b).

Throughput measures the average data rate (in bits) that can be sent between one user and another in a network (Henty, 2001). Upstream and downstream throughputs are the speed of data sent from the Client to the WLAN radio and the speed of data sent from WLAN radio to the Client respectively. Oghogho, et al, (2018b) has shown that upstream and downstream throughput are appreciably different hence predicting them separately gives a more accurate result.

Throughput has been found to be significantly accurate when predicted from Signal to noise ratio (SNR) only (Henty, 2001; Oghogho, 2018a). However other metrics like the number of users, the protocol used for transmission, the traffic type and the environment used for measurement appreciably influences the result.

Existing studies as reported in Oghogho et al, (2018a) presented models which were developed from a combination of field data collected across different environments. However, environment specific based models have been found to be more accurate than others which were developed without considering specific environments (Zia et al, 2016; Damaris et al; 2012). In this paper the author presents environment specific throughput models which were developed for better accuracy of throughput predictions in specific environments. Several researchers have provided models for predicting TCP throughput based on SNR only with reasonable accuracy. Oghogho, 2018a; provided a detailed review of throughput models based on SNR observed which applied cross layer modelling and considered single and multiple users, upstream and downstream throughput etc. Models considered by Oghogho 2018a; included those developed by Henty...
(2001), Metreaud, (2006), Oghogho et al, (2014), Oghogho et al (2015a), Oghogho et al (2015b), Oghogho et al, (2017) and Oghogho et al, (2018b). All of these models directly predict throughput from the SNR computed without specific consideration for particular types of environments. The need to more accurately predict throughput specifically for the different SNR observed.

The objective of this paper is to provide environment specific TCP upstream throughput models that more accurately predicts the TCP throughput of a single user for different SNR observed.

MATERIALS AND METHODS
The method used in Oghogho et al, (2014) and Oghogho et al, (2015a) was used in this work except that the models were developed for each specific environments (open corridor, small offices and free space) using only data collected in that environment. In this paper, open corridor, Small offices and free space are referred to as environment 1, environment 2 and environment 3 respectively. TCP upstream throughput data were collected for a single user on an IEEE 802.11b WLAN. The data was sorted for different categories of signals (General, Strong, grey and weak) as described in Oghogho et al, (2014) and Oghogho et al, (2015a). However the sorting was done separately for each environment unlike what was the case in Oghogho et al, (2014) and Oghogho et al, (2015a). Single User TCP upstream throughput models for IEEE 802.11b WLAN were statistically generated from the data using statistical package for social sciences (SPSS). All signals in environment 1 are in the strong signal range hence environment 1 does not have the second model which combines equations developed for strong, grey and weak signals respectively into one general equation. However for uniformity, model 1 is retained as an attachment to the name of the only model developed in environment 1.

Environment 2 consist of TCP upstream throughput data collected for all categories of signals (strong, grey and weak) hence two types of models were developed in environment 2. The first type of model was developed from the combined data in that environment while the second type of model was developed by first statistically generating model equations from data collected for each category of SNR and then combining the equations for the different signal categories to give one model equation for the entire SNR range. This was also done for environment 3.

Validation data was collected from other environments different from where the Field data used for generating the model equations were collected. They were used to validate the models developed. Values of root mean square errors, F tests and T tests were used to further decide whether the models should be accepted or rejected.

RESULTS AND DISCUSSIONS
The field data description, the developed models and the accompanied discussions are presented in this section using graphs and tables. Table 1 shows the statistical parameters of TCP_upT data collected for different SNR in all the environments. Fig. 1 shows averages of single user TCP_upT field data plotted against SNR for all signal ranges in the three environments considered. All signals for which throughput was measured in environment 1 (open corridor) were in the strong signal range (≥25dBm) hence only strong signals data were collected for this environment. However single User TCP upstream throughput data were collected for strong, grey and weak signals in environments 2 and 3. Environment is represented as “Env” in the Tables. From Table 1, it can be observed that the standard deviation (0.6387616 Mbps) and range (3.9Mbps) computed for the TCP_upT obtained for all values of SNR considered were low in environment 1. This implies that TCP_upT does not vary considerably in this environment for a single user on the network.

| Statistical Parameters | All SNR TCP_upT (Mbps) | Strong signals TCP_upT (Mbps) | Grey signals TCP_upT (Mbps) | Weak signals TCP_upT (Mbps) |
|------------------------|------------------------|-----------------------------|-----------------------------|-----------------------------|
| Sample Size (N)        | Env 1 | Env. 2 | Env 3 | Env 1 | Env. 2 | Env 3 | Env 1 | Env. 2 | Env 3 | Env 1 | Env. 2 | Env 3 |
| Mean (Mbps)            | 5.879 | 4.399 | 4.543 | 5.879 | 5.827 | 5.981 | 2.978 | 0.8104 | 1.1504 | 0.391 |
| Std. Error of Mean     | 0.025 | 0.074 | 0.100 | 0.025 | 0.033 | 0.029 | 0.088 | 0.08219 | 0.0819 | 0.046 |
| Median (Mbps)          | 6.065 | 5.500 | 5.860 | 6.065 | 6.00 | 6.145 | 2.735 | 0.4900 | 0.8600 | 0.320 |
| Mode (Mbps)            | 6.160 | 6.23 | 6.27 | 6.1600 | 6.23 | 6.27 | 2.61 | *0.17, 0.41 | *0.63, 0.87, 1.91 | 0.11 |
| Std. Deviation (Mbps)  | 0.638 | 1.969 | 2.446 | 0.6387 | 0.681 | 0.604 | 1.259 | 0.87372 | 0.8116 | 0.321 |
| Variance               | 0.408 | 3.985 | 5.985 | 0.408 | 0.464 | 0.365 | 1.587 | 0.763 | 0.659 | 0.104 |
| Skewness               | -2.363 | -0.661 | -0.983 | -2.363 | -1.97 | -2.793 | 0.547 | 1.870 | 1.671 | 1.015 |
| Std. Error of Skewness | 0.096 | 0.091 | 0.100 | 0.096 | 0.118 | 0.117 | 0.170 | 0.227 | 0.244 | 0.343 |
| Kurtosis               | 6.643 | -1.050 | -0.862 | 6.643 | 4.286 | 9.700 | -0.027 | 3.428 | 4.719 | 0.168 |
| Std. Error of Kurtosis | 0.192 | 0.181 | 0.200 | 0.192 | 0.236 | 0.234 | 0.339 | 0.451 | 0.483 | 0.674 |
| Range (Mbps)           | 3.9000 | 6.8300 | 6.70 | 3.900 | 3.78 | 3.68 | 5.83 | 4.40 | 5.06 | 1.18 |
High negative skewness (-2.363) was observed for TCP_{up}T. This means that the distributions of TCP_{up}T for single user have longer tails towards the left of its mean (5.879846Mbps). Multi modal distribution was absent for TCP_{up}T single user in environment 1. Since all TCP_{up}T data collected in environment 1 (open corridor) were in the strong signal range, environment 1 does not have TCP_{up}T data for grey and weak signals.

In environment 2, the standard deviation (1.9969Mbps) and range (6.8300Mbps) for TCP_{up}T data collected for all SNR were relatively high compared to that of environment 1. This implies that TCP_{up}T varies considerably in environment 2 than in environment 1 for a single user on the network over the entire range of signals. This difference in standard deviation observed between environment 1 and environment 2 is because in environment 1, TCP_{up}T data could be collected for only strong signals while in environment 2, TCP_{up}T data was collected for strong, grey and weak signals. For strong signals in environment 2, it was observed from Table 1 that the standard deviation (0.68137Mbps) and range (3.78Mbps) computed for the TCP_{up}T data for single user were low. This is very comparable with what was observed in environment 1 where all signals are in the strong range. This implies that TCP_{up}T does not vary considerably in environment 2 for a single user on the network when the signal is strong. Negatively skewed distribution (-1.976) was observed for TCP_{up}T strong signal data in environment 2 as was also observed in environment 1. This means that TCP_{up}T field data distribution has a longer tail towards the left of its observed mean of (5.8278Mbps) for strong signals. The observed range (3.78Mbps) for strong signal data only was appreciably lower than what was the case for all SNR data (6.8300Mbps) in environment 2. This is so because when the signal is strong, higher data rates are selected for data transmission but as signal degrades lower data rates are selected thereby increasing the TCP_{up}T range observed for all SNR (strong through grey to weak signals) compared with strong signals only. For grey signals single user data in environment 2, it can be seen from Table 1, that the standard deviation (1.259888Mbps) and range (5.83Mbps) for the TCP_{up}T single user data are high. This implies that when there is a single user on the network, TCP_{up}T vary considerably for grey signals. Low positively skewed distribution (0.547) was observed for TCP_{up}T data for grey signal in this environment. From the observed Kurtosis (-0.027), TCP_{up}T single user distribution has a flat peak and light tail for grey signals in environment 2. For Weak signals single user data in environment 2, it can be seen from Table 1 that the standard deviation (0.81162Mbps) for TCP_{up}T is low for weak signals. This implies that when there is a single user on the network, TCP_{up}T does not vary considerably for weak signals in environment 2. High positively skewed distribution (1.671) was observed for TCP_{up}T weak signal data. The observed Kurtosis (4.719) shows that TCP_{up}T single user distribution has a sharp peak and heavy tails compared with normal distribution for weak signals. For All SNR single user TCP_{up}T data in environment 3, it can be seen from Table 1 that the standard deviation (2.44640Mbps) and range (6.7Mbps) obtained for the entire range of signals considered are higher unlike what was the case for environment 1. The standard deviation was also higher than that of environment 2. This implies that TCP_{up}T vary considerably in free space environment for a single user on the network over the entire range of signals than in small offices and open corridor environments. This difference can be explained as follows. The grey and weak signal values (which usually introduce large variations into measured TCP_{up}T values are observed at greater distances from the WLAN radio in free space than what is the case for small offices. The differences in distances (which provide the same value of SNR in the different environments) and the obstacles in the small offices environments introduce the slight variations in standard deviations observed. Since there is a single user on the network, the WLAN radio, server and clients are still able to use high data link rates at
random even when signal has become grey or weak thus allowing the possibility of large variations for single user based on differences in the different environments. An obvious reason for the difference in standard deviation and range between TCP-up,T data for environment 3 and environment 1 occurs because data were collected for only strong signals in environment 1 while in environment 3, TCP-up,T data were collected for strong, grey and weak signals. Negatively skewed distribution (-0.983) was observed for All SNR for strong, grey and weak signals. Negatively skewed distribution (-2.793) was observed for TCP-up,T distribution for the signal data in environment 3 for single user. For strong signals single user TCP-up,T data in environment 3, it can be seen from Table 1 that the standard deviation (0.60427Mbps) and range (3.68Mbps) obtained were low. This is very comparable with what was observed in environment 1 and environment 2 for strong signals. This implies that TCP-up,T does not also vary considerably in environment 3 for a single user on the network when the signal is strong. Negatively skewed distribution (-2.793) was observed for TCP-up,T strong signal data in environment 3. From the observed Kurtosis (9.700) for TCP-up,T single user data the distribution will have narrow peaks for strong signals in environment 3.

For grey signals single user data in environment 3, it can be seen from Table 1 that the standard deviation (0.87372Mbps) and range (4.40Mbps) for TCP-up,T were appreciably low for grey signals. This is a big deviation from what was observed in environment 2 where the standard deviation and range for TCP-up,T were high for grey signals. This is so because for single user, the WLAN client selects lower data rates more consistently when signal has become grey thus resulting in low TCP-up,T variation. There is a greater probability that the WLAN system continuously selects lower data rates for transmission in environment 3 (free space) compared with environment 2 (small offices) when signal is in the grey range. Note that in environment 3, grey signals occur when Client is very far from the WLAN radio unlike what is the case in environment 2 where the obstructions inside the building allows grey signals to be measured at distances not too far away from the WLAN radio. Positively skewed distribution (1.870) was observed for TCP-up,T data in environment 3 for grey signals. From the observed Kurtosis (3.428), TCP-up,T, has an arrow peak and heavy tails for grey signals in environment 3 for a single user on the network.

For weak signals single user data in environment 3, it can be seen from Table 1 that the standard deviation (0.32188Mbps) and range (1.18Mbps) for TCP-up,T were low for weak signals. This implies that when there is a single user on the network, TCP-up,T does not vary considerably, a trend that was also observed in environment 2. However for single user, the deviations observed for TCP-up,T in environment 3 is slightly lower than that of environment 2 for weak signals. TCP-up,T does not vary considerably for weak signals in this environment because when the signal has become weak for a single user, the WLAN Client which sends upstream data consistently uses low data rates for transmission hence the variation is low. Positively skewed distribution (1.015) was observed for TCP-up,T data for weak signals in environment 3 for a single user. From the observed Kurtosis (0.168) for TCP-up,T, the distribution has a narrow peak and heavy tails for weak signals in environment 3. Environment 1 is an open corridor environment. All signals in environment 1 are in the strong signal range, hence environment 1 does not have the second model which combines equations for strong, grey and weak signals. However for uniformity, model 1 is retained as an attachment to the name of the only model developed in environment 1.

Key parameters of all the developed models in this paper are available in Table 2. The model equations developed allows the network designer, or the WLAN user to estimate the TCP upstream throughput directly from SNR values computed from received signal strength indication (RSSI) measured on site. Equation 1 shows the developed model equation for Environment 1 Single User TCP Upstream Throughput Model 1 ($Env_{1}SU\ TCP_{up,t} Model_{1}$). $\alpha_{1}$ is the coefficient of the model.

\[
Env_{1}SU\ TCP_{up,t} Model_{1} = f(SNR) = \begin{cases} 
\frac{SNR a_{1} - 0.6Mbps}{SNR a_{1}} & \text{SNR} > 64dB \\
\frac{6.07Mbps}{SNR} & \text{SNR} < 65dB
\end{cases}
\]

Throughput Model 1($Env_{2}SU\ TCP_{up,t} Model_{1}$). $\alpha_{i}$ is the coefficient of the model.

Equation 2 shows the developed model equation for Environment 2 Single User TCP Upstream

\[
Env_{2} SU\ TCP_{up,T} Model_{1} = f(SNR) = \begin{cases} 
\frac{SNR a_{3} - 0.6Mbps}{SNR a_{3}} & \text{SNR} > 41dB \\
\frac{4.2Mbps}{SNR} & \text{SNR} > 18dB \\
\frac{1Mbps}{SNR} & \text{SNR} < 19dB
\end{cases}
\]

Throughput Model 2 ($Env_{2}SU\ TCP_{up,T} Model_{2}$).
**Environment Specific TCP Upstream Throughput...**

$Env_{SU \ TCP_{upT}} \ Model_2$ is a combination of TCP\textsubscript{upT} single user models developed in the strong, grey and weak signal ranges with parameters presented in Table 2.

$Env_{SU \ TCP_{upT}} \ Model_2 = f(SNR) = \begin{cases} 6.15 \text{Mbps} & \text{SNR} \geq 61 \\ \frac{a_1 \cdot SNR + a_2 \cdot SNR^2 + (C - 1) \text{Mbps}}{25dB < SNR < 18dB} & \text{SNR} < 19dB \\ 0.1 \text{Mbps} & \text{SNR} \leq 17dB \end{cases}$

Equation 4 shows the developed model equation for $Env_{SU \ TCP_{upT}} \ Model_2$. $a_1, a_2$ are coefficients and $C$ is a constant of the equation.

$Env_{SU \ TCP_{upT}} \ Model_1 = f(SNR) = \begin{cases} 6.4 \text{Mbps} & \text{SNR} \geq 61 \\ a_1 \cdot SNR + a_2 \cdot SNR^2 + (C - 1) \text{Mbps} & 40dB < SNR < 16dB \\ 0.1 \text{Mbps} & \text{SNR} < 17dB \end{cases}$

Equation 5 shows the developed model equation for $Env_{SU \ TCP_{upT}} \ Model_1$. $a_1, a_2$ are coefficients and $C$ is a constant of the equation.

**Table 2: Parameters of Developed Models and Test Results**

| SNR Category | Model 1 Coefficient | Model 2 Coefficient | $R^2$ Value |
|--------------|---------------------|---------------------|-------------|
| Strong Signals | $a_1$ = 34.078 | $a_1$ = 233.885 | 0.886 |
| Grey Signals  | $a_2$ = -27.354 | $a_2$ = 9.907 | 0.992 |
| Weak Signals  | $a_3$ = -23.785 | $a_3$ = -10.254 | 0.992 |

$Env_{SU \ TCP_{upT}} \ Model_1$ is a combination of TCP\textsubscript{upT} single user models each developed in the strong, grey and weak signal ranges with parameters presented in Table 2. Equation 5 shows the developed model equation for $Env_{SU \ TCP_{upT}} \ Model_2$. $a_1, a_2$ are coefficients and $C$ is a constant of the equation.
Table 3: RMS Error values for our TCP\textsubscript{up}T Models and other models for Single user.

| Environment 1 RMS Errors Comparison | Model description | All SNR | Strong Signals | Grey Signals | Weak Signals |
|-------------------------------------|-------------------|---------|----------------|-------------|-------------|
| 1 SU TCP\textsubscript{up}T Model\textsubscript{1} | Oghogho 2015 General TCP\textsubscript{up}T Single User Model | 0.370496 | 0.370496 | Not applicable | Not applicable |
| 2 Oghogho 2015 SNR Categorized TCP\textsubscript{up}T Single User Models | Oghogho 2015 SNR Categorized TCP\textsubscript{up}T Single User Models | 0.822566 | 0.822566 | Not applicable | Not applicable |
| 3 Metreaud Multi tap Model C | Metreaud Multi tap Model C | 0.436222 | 0.436222 | Not applicable | Not applicable |
| 4 Metreaud Multi tap model B | Metreaud Multi tap model B | 0.419134 | 0.419134 | Not applicable | Not applicable |
| 5 Metreaud Multi tap model A | Metreaud Multi tap model A | 0.382111 | 0.382111 | Not applicable | Not applicable |
| 6 Metreaud One tap Constant Channel | Metreaud One tap Constant Channel | 0.439551 | 0.439551 | Not applicable | Not applicable |
| 7 Henty Single User Exponential Model | Henty Single User Exponential Model | 0.356074 | 0.356074 | Not applicable | Not applicable |
| **Best two models in each category** | Model (8, 1) Model (8, 1) |

| Environment 2 RMS Errors Comparison | Model description | All SNR | Strong Signals | Grey Signals | Weak Signals |
|-------------------------------------|-------------------|---------|----------------|-------------|-------------|
| 1 SU TCP\textsubscript{up}T Model\textsubscript{1} | Oghogho 2015 General TCP\textsubscript{up}T Single User Model | 0.764418 | 0.80596 | 1.000892 | 0.230968 |
| 2 SU TCP\textsubscript{up}T Model\textsubscript{2} | Oghogho 2015 SNR Categorized TCP\textsubscript{up}T Single User Models | 0.429866 | 0.311334 | 0.986266 | 0.299671 |
| 3 Oghogho 2015 SNR Categorized TCP\textsubscript{up}T Single User Models | Oghogho 2015 SNR Categorized TCP\textsubscript{up}T Single User Models | 0.530945 | 0.456634 | 0.971399 | 0.478158 |
| 4 Metreaud Multi tap Model C | Metreaud Multi tap Model C | 1.880661 | 0.583619 | 3.708812 | 3.391684 |
| 5 Metreaud Multi tap model B | Metreaud Multi tap model B | 1.760798 | 0.570354 | 3.689851 | 3.095769 |
| 6 Metreaud Multi tap model A | Metreaud Multi tap model A | 1.855241 | 0.533089 | 3.746734 | 3.317637 |
| 7 Metreaud One tap Constant Channel | Metreaud One tap Constant Channel | 2.462523 | 0.590393 | 3.718297 | 5.156534 |
| 8 Henty Single User Exponential Model | Henty Single User Exponential Model | 1.441237 | 0.500779 | 3.353917 | 2.152993 |
| **Best two models in each category** | Model (2, 1) Model (4, 2) Model (3, 2) Model (1, 2) |

| Environment 3 RMS Errors Comparison | Model description | All SNR | Strong Signals | Grey Signals | Weak Signals |
|-------------------------------------|-------------------|---------|----------------|-------------|-------------|
| 1 SU TCP\textsubscript{up}T Model\textsubscript{1} | Oghogho 2015 General TCP\textsubscript{up}T Single User Model | 0.844438 | 0.916811 | 0.825938 | 0.383037 |
| 2 SU TCP\textsubscript{up}T Model\textsubscript{2} | Oghogho 2015 General TCP\textsubscript{up}T Single User Model | 0.588809 | 0.520786 | 1.069935 | 0.311829 |
| 3 Oghogho 2015 SNR Categorized TCP\textsubscript{up}T Single User Models | Oghogho 2015 SNR Categorized TCP\textsubscript{up}T Single User Models | 0.974717 | 0.856175 | 1.753183 | 0.692781 |
| 4 Oghogho 2015 SNR Categorized TCP\textsubscript{up}T Single User Models | Oghogho 2015 SNR Categorized TCP\textsubscript{up}T Single User Models | 1.385548 | 0.58797 | 3.247595 | 1.723158 |
| 5 Metreaud Multi tap Model C | Metreaud Multi tap Model C | 2.392163 | 0.577401 | 4.81028 | 4.277831 |
| 6 Metreaud Multi tap model B | Metreaud Multi tap model B | 2.269292 | 0.565033 | 4.790663 | 3.844934 |
| 7 Metreaud Multi tap model A | Metreaud Multi tap model A | 2.32983 | 0.530729 | 4.821098 | 4.067888 |
| 8 Metreaud One tap Constant Channel | Metreaud One tap Constant Channel | 2.687766 | 0.583744 | 4.820089 | 5.809439 |
| 9 Henty Single User Exponential Model | Henty Single User Exponential Model | 1.936944 | 0.504687 | 4.468296 | 2.869512 |
| **Best two models in each category** | Model (2, 1) Model (9, 2) Model (1, 2) Model (2, 1) |

*RMS error is estimated for all the models using TCP upstream throughput validation data for each specific environment.

To test the developed models the author defines the following hypothesis: Null hypothesis 1; H\textsubscript{0} = Proposed TCP\textsubscript{up}T model does not fit the data well and the slope of the regression line does not differ significantly from zero for a single user on the network. (This means that TCP\textsubscript{up}T is not significantly dependent on SNR for a Single User on the network). Alternative hypothesis 1; H\textsubscript{1} = Proposed TCP\textsubscript{up}T model fits the data well and the slope of the regression line differs significantly from zero for a single user on the network. (This means that TCP\textsubscript{up}T is significantly dependent on SNR for a Single User on the network).
It can be seen from Table 3 that the TCP_{up}T models developed in this work performed better than other similar TCP_{up}T models developed in previous work. This has justified the need for carrying out this work. However the second model developed in this work (by first statistically generating model equations from data collected for each category of SNR and then combining the equations for the different signal categories to give one model equation for the entire SNR range) performed better in most cases considered as seen in Table 3. Fig. 2, Fig. 3, and Fig.4 show the graphs of TCP_{up}T developed in this work plotted against SNR along with TCP_{up}T Validation data average, and the other similar models with which they were compared in environment one, two and three respectively. It can also be seen that the models...
developed in this work follows the validation data more closely than the other models earlier developed in all the environments considered.

**Conclusion:** In this paper, environment specific TCP Upstream Throughput (TCP_{up}T) models based on SNR for a single user in an IEEE 802.11b WLAN have been presented. TCP_{up}T data for strong, grey and weak signals and different QoS traffic were collected for each environment and used to develop the respective models which passed the F and T tests and performed better than other similar existing models considered when the RMS errors were compared. These models serve as a useful predictive tool for WLAN installers and network designers needed to make better informed decision.

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