Using Fuzzy Logic to Predict Millimeter Wave Communication Link on Varying Weather Conditions

†Ifrah Ahmed, †Zahid Rauf, †Bushra Naeem, †Jan Muhammad, ††Shabbar Naqvi, †Rahila Umer, †Hamayoun Shahwani, †Raja Asif Wagan

† Faculty of Information and Communication Technology,
Balochistan University of Information Technology Engineering and Management Sciences (BUITEMS), Quetta, Pakistan
†† Department of Computer Systems Engineering, Balochistan University of Engineering and Technology Khuzdar Pakistan
Corresponding author:

Summary
Climate conditions can have enormous effects on communication systems. Knowing the factors which affects the transmission can help in planning and designing networks. Rain, cloud, gas and fog are some of the main factors which can cause signal attenuation; but cloud attenuation is the main impairment factor for mm wave signals propagating through the atmosphere. This is due to the structure of clouds and higher probability of its occurrence. Several empirical models are proposed in literature to study the impact of cloud attenuation. However, there are times when the measurable data is not available then we need the decision of an intelligent fuzzy based support system which enables us to determine the effect of weather parameters on the communication which further leads to check the possibility of communication at cloudy weather. This paper presents an intelligent fuzzy logic system for Salonen and Uppala, Mass Absorption and DAH cloud attenuation models to predict the strength of link communication in given weather conditions in the absence of empirical data. The fuzzy controller uses frequency, elevation angle and liquid water content as input parameters.

Key words: Cloud attenuation, prediction models, fuzzy logic, millimeter (mm) wave

1. Introduction

Clouds are of different types and are formed when moist air goes upward. When the air rises it becomes colder. Finally, the air can't hold all of the vapors in it, so some of the water vapor goes to the condensation process to form water droplets. Clouds physical features are not stationary which means they change all the time. At any given time, the earth's surface is covered 50% with clouds statistically [1] which leads us to the impact that they have. As clouds are present most of the time so attenuation occurs due to clouds became an important factor [2]. Cloud attenuation is a function of mainly liquid water content, temperature, frequency and elevation angle which can be measure through different available resources. For calculation of cloud attenuation many prediction models already exist in the literature.

The initial efforts to develop mathematical models for cloud attenuation were put forward by Mie and Rayleigh and initiated by [3]. These initial models are based on mathematical equations and hence can't accommodate empirical data. Later the empirical models were independently developed, such as those proposed by Dintelmann and Ortgies [4] and Altshuler and Marr [5], [6], calculating the cloud attenuation using the surface absolute humidity as an input parameter. The coefficients of these model expressions depend on actual measurements. The methodology to predict cloud attenuation proposed by Dissanayake et al. [7] is the worth mentioning and is based on occurrence probability of four different cloud types which come from cloud cover atlas [8]. The model proposed by Salonen and Uppala in [9] also known as Teknillinen KorkeaKoulu (TKK) which shows the good prediction accuracy also accepted in Recommendation ITU-R P.840-6. Mass absorption coefficients Model which is an alternative approach of Salonen and Uppala proposed by Luini and Capsoni [10], [11].

Many experimental studies have been conducted on mm wave atmospheric attenuation. Based on these studies cloud cover statistic and cloud attenuation for the African tropical rain forest climate is investigated [12]. The use of meteorological data available worldwide are used for estimation due to clouds, water vapor and oxygen in Belgium and India [13]. In [14], [15] different aspect of clouds e.g. drop size, temperature, liquid water content and dielectric constant with respect to cloud attenuation is discussed and its effects on satellite communication is given. The authors in [16], presented the effect of

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frequency, elevation angle and liquid water content on cloud attenuation for several empirical models. Moreover, the attenuation loss results are analyzed with theoretical Empirical Cumulative Distribution Function equation.

The empirical approaches to cloud attenuation have been used to evaluate cloud impairments, however in the absence of complete knowledge of empirical data, the attenuation and its affects can be taken by predictions only. Therefore, to deal with weather impacted link quality with insufficient data, it is important to have intelligent link prediction systems. Researchers have used fuzzy logic as a strong prediction tool in predicting weather related communication impairments [17], [18].

In [19] a fuzzy logic is used to improve the received signal over satellite communication in digital video broadcasting satellite system which is affected by rain. In [20] a combined effect of propagation impairment in slant path is considered and then intelligent weather aware technique is applied which uses fuzzy logic to maintain the quality of service in heavy rainfall at higher frequency band. In [21], [22] ITU-R model is used to calculate the accurately gaseous absorption, fog, cloud and tropospheric scintillation and then the data is applied to intelligent system to main the quality of service. In [23] an intelligent algorithm is derived which is capable to improve the signal in changing weather so that the end users get the desired signal. In [24], [25] a rule-based technique, the fuzzy logic is used to measure the atmospheric temperature which is an application of this technique can be used in the area of operational meteorology. In this research work we propose an intelligent fuzzy system for Salonen and Uppala, Mass Absorption and DAH cloud attenuation models to predict the strength of link communication in given weather conditions in the absence of empirical data.

Rest of the paper is organized as follows: section II, presents the proposed fuzzy system for commonly used prediction models namely Salonen and Uppala, Mass Absorption and Dissanayake-Allnutt-Haidara (DAH). Section III, demonstrates the simulated results of the proposed system model with different parameters. Finally, section IV, presents the conclusions of this research work.

2. Proposed Fuzzy System for Weather Forecast

Fuzzy logic which is also sometimes called diffuse logic is based on fuzzy set theory, which is a generalization of classical set theory [26]. Fuzzy logic deals with the degree of membership and degree of truth. It takes multiple values between 0 and 1 [27], [28]. The two types of fuzzy Inference system are Mamdani and Sugeno [29]. In this research Mamdani control system is used because it is most commonly use type and it maps the output as the membership function between 0 and 1 while Sugeno control system shows output only on constant values which is not acceptable.

2.1 Input

The input variables in fuzzy control system are mapped by membership function. Three input variables are used which are Liquid water content (w), elevation angle (θ_e) and frequency (*f*). The range of w is 0.1mm to 0.9mm. The triangular membership function is used as the membership function and the w fuzzy sets defined are: very low (VL 0.1 to 0.3), low (L 0.3 to 0.5), medium (M 0.5 to 0.7) and high (H 0.7 to 0.9). The θ_e has a range of 10 to 90 degree. The membership function used is zmf and is categorized into four different classes with following parameters: high (H 10° to 30°), medium (M 30° to 50°), low (L 50° to 70°) and very low (VL 70° to 90°). Figure 2 shows the modeling of elevation angle (θ_e) input parameter. The other important input parameter is *f* with a range of 30 to 60 GHz and the membership function chosen for this parameter is smf with four classes which are: very low (VL 30 to 37.5 GHz) , low (L 37.5 to 45 GHz), medium (M 45 to52.5 GHz) and high (H 52.5 to 60 GHz).

2.2 Output

The output is triangular shape which tells the possible degree of communication. Every model has its own output range. The intelligent weather-based link prediction is developed using four thresholds which correspond to four link status conditions; impossible, partly, good and excellent respectively as shown in Fig. 1. The output ranges of communication level were calculated relatively comparing them with the attenuation values of the cloud attenuation models. The range of Salonen and Uppala model is from 0.4 to 4 therefore the corresponding output of communication possibility was categorized using triangular wave distribution. Similarly, for Mass Absorption and DAH model the range is 0.4 to 5 and 0.1 to 2.9 respectively.

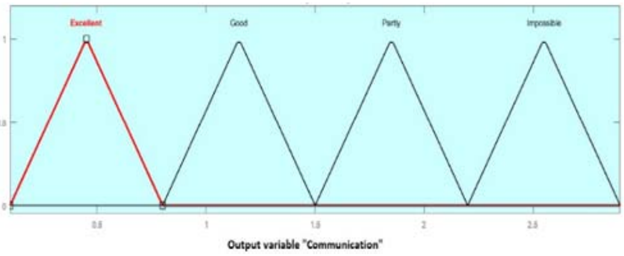

Fig. 1. Fuzzy output variable "Communication".

2.3 Fuzzy System Rules

Human beings make many rules in everyday life, which help them to take the decisions. These decisions are similar to the machine-like decisions which are based on the *if, else, or, and then* statements using antecedents and consequence. Fuzzy rules are written to map the fuzzy input variables to the fuzzy output variables based on the logical rules.

Based on the proposed fuzzy model for the prediction of communication according to the liquid water content (*w*) and frequency (*f*), a total of 32 rules for two input parameters are composed. Considering the relation of communication with the w and θ_e, the communication level is predicted to be excellent if both parameters are low. Further, considering the fuzzy logic controller for three inputs, i.e. the f, θ_e and w if all three parameters are low, again an excellent communication can be predicted. There are 64 rules for three-input fuzzy system.

Different rules are designed for the two-input and three-input fuzzy systems. The fuzzy engine using three parameters must consider all three parameters while making decision of communication, since the decisions are dependent on each parameter. For instance, rules for two and three input parameters can be written as follows:

Example rule for two-input parameters:

- If w is VL and f is VL then communication is Excellent.
- If w is L and f is L then communication is good.
- If θ_e is VL and f is H then communication is impossible.

Example rule for three-input parameters:

- If w is H and θ_e is H and f is H then communication is Impossible.
- If w is VL and θ_e is VL and f is L then communication is good.
- If w is M and θ_e is VL and f is M then communication is partly possible.

3. Simulation Results

This section presents the simulated results of the proposed fuzzy system for Salonen and Uppala, Mass absorption and DAH models with two and three parameter study which is explained in succeeding sub-sections. The results are achieved by considering the frequency f range of 30 to 60 GHz, elevation angle θ_e of 10 to 90 degree and liquid water content from 0.1 to 0.9 mm as preliminary input parameters.

3.1 Two Input Parameters

Prediction of communication according to the changes made in frequency (*f*) and liquid water content (*w*) for the three cloud attenuation models are shown in Figs. 2, 3 and 4. In this system 32 rules have been defined for two input fuzzy controller system. Fig. 2 shows that for the Salonen and Uppala model, communication varies only as a result of w and f using two parameters.

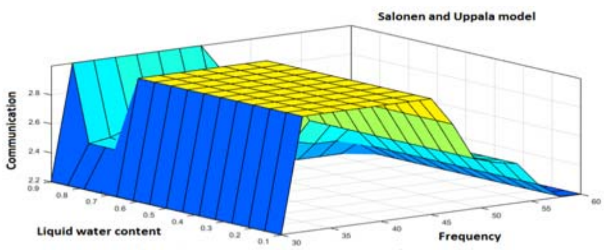

Fig. 2. Frequency vs Liquid water content of Salonen and Uppala model using two input parameters

Similarly, the same 32 rules are applied for Mass Absorption and DAH models for the prediction of communication. It can be seen from figs. 3 and 4 that at lower w and f the communication is maximum and as the value of both parameters increases, the communication decreases. The graph falls for some cases when any of the parameters value lies in the impossible range, leading to impossible communication.

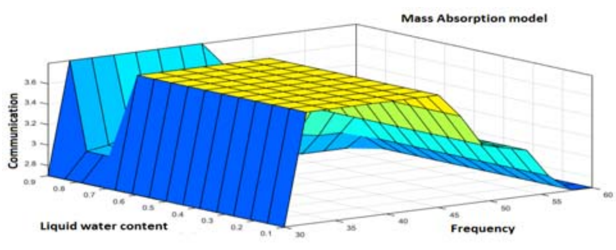

Fig. 3. Frequency vs Liquid water content of Mass Absorption model using two input parameters.

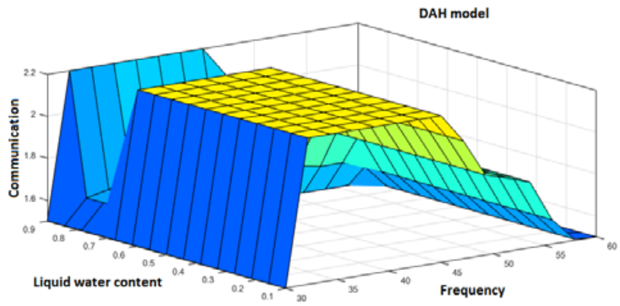

Fig. 4. Frequency vs Liquid water content of DAH model using two input parameters

Prediction of communication according to the changes made in other two parameters i.e. frequency f and elevation angle (θ_e) for the three cloud attenuation models are shown in Figs. 5, 6 and 7. Here also 32 rules with reference to above two parameters have been defined for the proposed fuzzy controller system. For Salonen and Uppala model as shown in Fig. 5, the up and downs of communication level can be seen. At lower θ_e i.e. 90° and lower f i.e. 30 GHz the communication is maximum, and communication is minimum at higher θ_e and f.

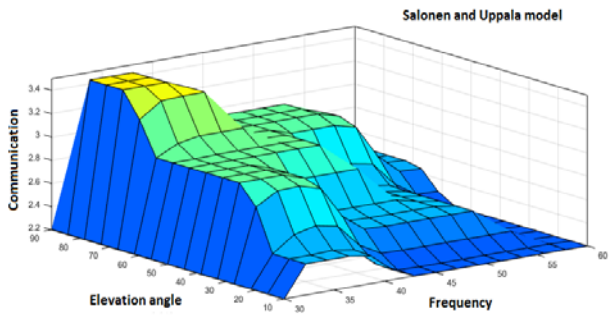

Fig. 5. Frequency vs Elevation angle of Salonen and Uppala model using two input parameters

Fig. 6 depicts the 3-dimensional vision of Mass Absorption model using two input parameters. The communication exceeds only when θ_e is high, and f is low. The communication level reduces when f decreases and elevation angles increase. It can be seen that elevation angle has inverse effect on communication while frequency has a direct effect.

Fig. 7 illustrates the output of DAH model as a result of using elevation angle and frequency. The level of communication has increases and decreases as the values of both the parameters changes. The communication is at maximum value when θ_e is highest i.e. 90° and f is at lowest i.e. 30GHz.

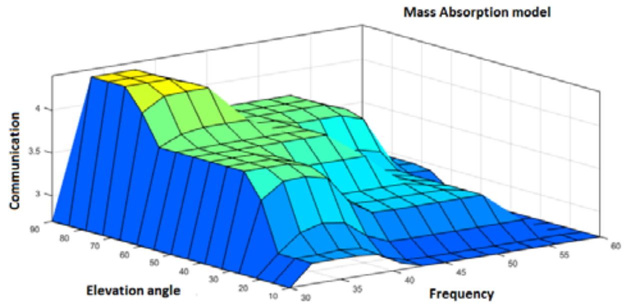

Fig. 6. Frequency vs Elevation angle of Mass Absorption model using two input parameters

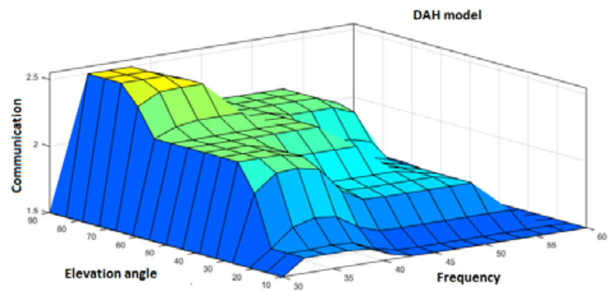

Fig. 7. Frequency vs Elevation angle of DAH using two input parameters

3.2 Three Input Parameters

The Figs. 8, 9 and 10 show the comparison of Salonen and Uppala, Mass Absorption and DAH models, respectively, between elevation angle (θ_e), liquid water content (w) and frequency (f) through the fuzzy logic inference system. If the LWC is very low and the length of θ_e through the clouds is small and f is also very low then the communication will be excellent. In this system, 64 rules have been defined for three input fuzzy controller system. The graph shows up and downs according to the values of parameters.

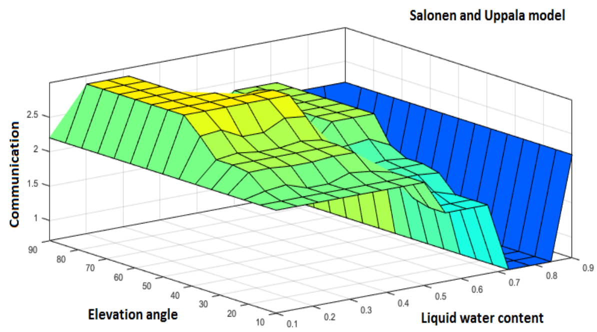

Fig. 8. Elevation angle vs Liquid water content of Salonen and Uppala model using three input parameters

All the three input parameters are added together to the fuzzy system to evaluate the communication level more accurately. At lower elevation angle , liquid water content and frequency, the communication is Excellent. If any of the parameter goes toward higher values then communication decreases as defined in the rules.

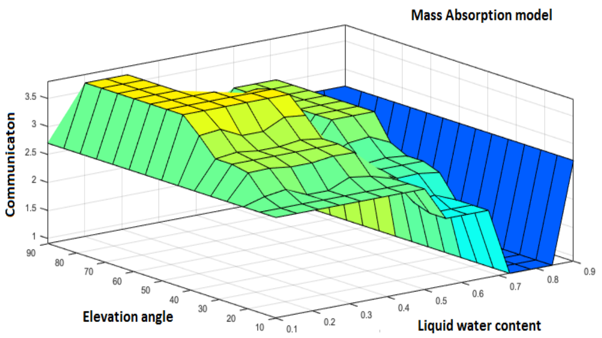

Fig. 9. Elevation angle vs Liquid water content of Mass Absorption model using three input parameters

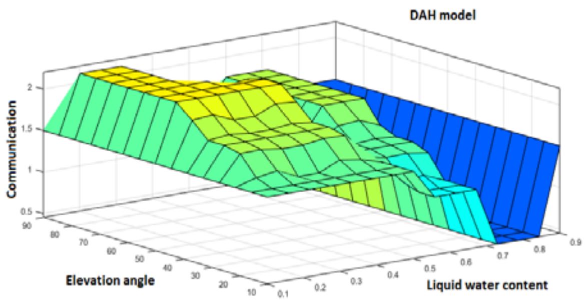

Fig. 10. Elevation angle vs Liquid water content of DAH model using three input parameters

3.3 Scenario Analysis

A scenario analysis is performed to study the obtained output across expected output for the proposed fuzzy system. Random ten test values are taken for two and three input parameters across each model and analysis has been performed.

a. Case Study for Salonen and Uppala model for two input parameters:

For Salonen and Uppala model the system is tested at the different values shown in Table 1. It was seen 8 values at fuzzy controller matches the expected output, where as two values at serial no. 2 and 4 mis-matches the expected output. The efficiency of the controller is calculated by the following formula [30]:

$$= \frac{expected\ output}{output\ at\ fuzzy\ controller} \times 100\% \quad (1)$$

so the calculated efficiency is (8/10)×100= 80%

Table 1. Testing analysis of Salonen and Uppala model for two input parameters

S No.	Inputs			Rules	Output at fuzzy controller	Expected output according to fuzzy
	w	θ_e	f			
1	0.1	-	45	If w is VL and f is L then communication is Good	2.2 Good communication	Good communcation
2	0.9	-	42	If w is H and f is L then communication is Impossible	2.22 Good Commnication	Impossible communication
3	0.3	-	34	If w is L and f is VL then communication is Good	2.47 Good communication	Good communication
4	0.3	-	36	If w is VL and f is VL then communication is Excellent	2.47 Good communiction	Excellent communicition
5	0.6	-	40	If w is M and f is low then communication is Good	2.32 Good communiction	Good communicition
6	-	71	37	If θ_e is VL and f is VL then communication is Excellent	3.5 Excellent communiction	Excellent communicition
7	-	54	37	If θ_e is L and f is VL then communication is Good	3 Good communication	Good communicition
8	-	80	37	If θ_e is VL and f is VL then communication is Excellent	3.5 Excellent communiction	Excellent communicition
9	-	61	44	If θ_e is L and f is L then communication is Good	3 Good communication	Good communicition
10	-	90	53	If θ_e is VL and f is M then communication is Good	2.2 Good communication	Good communicition

Similarly, for Mass Absorption and DAH models the system is tested at the different values, however, due to space limitations the tables are not included. The accuracy of all the three models can be graphically represented.

Frequency with Liquid water content and alternately frequency with elevation angle are taken as two input parameters. The ten test values for each model are randomly taken from both couple of two input parameters to see disparity among correct predictions and results are shown graphically in Fig. 11. It can be seen that 8 points of Salonen and Uppala model and DAH model matches as per expectations so efficiency of both models is 80% and efficiency of Mass Absorption model is 70% with two input parameters.

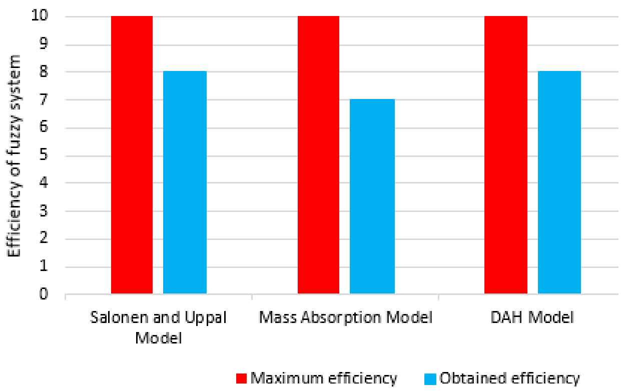

Fig. 11. Graphical representation of controller accuracy for two input parameters

b. Case Study for Salonen and Uppala model for three input parameters:

For Salonen and Uppala model the system is tested at 10 values shown in Table 6. It was seen that all the values at fuzzy controller matches the expected output so the efficiency is 100%. Similarly for Mass Absorption and DAH models the system is tested at the different values, It was observed that for both models, the efficiency was 100% because all the values matches the expected output of the fuzzy controller system. Due due to space limitations the tables are also not included.

Random ten test values are taken for each model using two and three input parameters and accuracy of proposed fuzzy controller is checked. It is seen that there is high efficiency in three input fuzzy controller system as shown in Fig. 12 and there is low efficiency in two input fuzzy controller system. All the models show 100% efficiency in given scenario and can vary but expected to remain on higher side. The reason is that the more factors involve, more accurately the systen is able to predict the communication.

Table 2. Testing analysis of Salonen and Uppala model for two input parameters

S. No.	**Inputs**			**Rules**	**Output at fuzzy controller**	**Expected output accordin g to fuzzy**
	w	θ_e	f			
1	0.5	50	45	If w is L, θ_e is L and f is also L then communication is Good	2.2 Good communica tion	Good communc ation
2	0.3	62	37	If w is VL, θ_e is L and f is VL then communication is Good	3.0 Good Commnicat ion	Good communc ation
3	0.2	71	37	If w is VL, θ_e is VL and f is also VL then communication is Good	3.5 Excellent communica tion	Excellent communi cation
4	0.5	38	48	If w is M, θ_e is M and f is also M then communication is Partly	2.0 Partly communicti on	Partly communi ction
5	0.7	38	48	If w is H, θ_e is M and f is M then communication is Impossible	0.7 Impossible communicti on	Impossibl e communi ction
6	0.8	28	54	If w is H, θ_e is H and f is also H then communication is Impossible	0.7 Impossible communicti on	Impossibl e communi ction
7	0.5	58	48	If w is L, θ_e is L and f is M then communication is Good	2.5 Good communica tion	Good communi ction
8	0.3	67	40	If w is VL, θ_e is L and f is L then communication is Good	2.99 Good communica tion	Good communi cation
9	0.7	34	59	If w is H, θ_e is M and f is H then communication is Impossible	0.7 Impossible communicti on	Impossibl e communi ction
10	0.3	82	51	If w is L, θ_e is VL and f is M then communication is Paartly	2.0 Partly communica tion	Partly communi ction

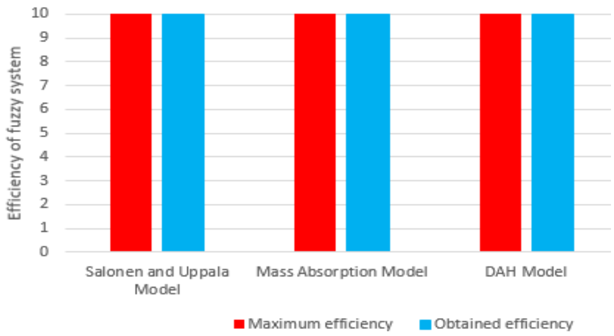

Fig. 12. Graphical representation of controller accuracy for three input parameters

Conclusion

The assessment of the impairments on signal propagation at mm waves is significant. There are times when the empirical data is not available and therefore we need the decision support system, fuzzy logic controller. In this study we proposed an intelligent fuzzy system for Salonen and Uppala, Mass Absorption and DAH cloud attenuation models to predict the strength of link communication in given weather conditions in the absence of empirical data. Different scenarios and their efficiency were calculated for two input and three input fuzzy system. It was also concluded that the more the factors involved, the more accurately the systen was able to predict the communication link quality.

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