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Mitigating Rain Attenuation on Wireless Communication Link using Adaptive Power Control

Nwaogu C. C., Amadi A. O., Alozie I. S

Abstract: **The quality of radio communication between wireless devices varies significantly with time and environment. This phenomenon indicates that to different environmental/weather conditions control solutions exist using adaptive power control. Wireless communication systems which use static transmission power, transmission range, and link quality, might not be effective in the physical world. To address this issue, adaptive transmission power control that adapts to external changes is necessary. This work presents a mitigation technique using Adaptive transmission Power control (ATPC). In ATPC, each node builds a model for each of its neighbors, describing the correlation between transmission power and link quality. With this model, we employ a feedback-based transmission power control algorithm to dynamically maintain individual link quality over time. PID controller gives a better response in adaptive power control**

Keywords: Adaptive, Control, Power, Transmit, Wireless.

I INTRODUCTION

In recent years, there has been a high demand for high data rates, wide bandwidths and high availability of satellite communication signals for multimedia services. Due to this great demand and over congestion of the Ku-frequency band, satellite communication is now exploiting the Ka (20/30 GHz) band and above [26][18][20]. However, microwave signals propagating in these bands suffer from more rain attenuation in comparison to the conventional C and Ku band. Therefore, in order to reduce the effect of attenuation on the communication links, several fade mitigation techniques exist.The fade mitigation techniques include diversity protection schemes, adaptive power-control and adaptive-wave techniques [8][20]. Among the fade mitigation techniques, adaptive transmit power control (ATPC) has been found to be the most efficient of all [20]. The adaptive transmit power control is not new, but this approach is quite unique. In state-of-art research, many transmission power control solutions use a single transmission power for the whole network, not making full use of the configurable transmission power provided by radio hardware to reduce energy consumption.

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Some networks take the configurable transmission powers into consideration. They either assume that each node chooses a single transmission power for its area of coverage [5][14][15][16], it is also referred to as node-level solutions. In this paper the approach is where nodes use different transmission powers for different neighbors or coverage areas [16][17], which is called neighbor-level solutions. While this second solution provides a solid foundation for this work, ATPC goes further to support packet-level transmission power control in a pairwise manner.

The power control approach aims at maintaining a desired received signal level by varying the power of the transmitter. This is one of the simplest, most commonly used and most efficient rain attenuation mitigation techniques available, and will be explored in this paper. Several power management schemes have been proposed for satellite communication systems [19]. In such a system, the bit-error-rate (BER) is adjusted by controlling the transmitter power according to the importance of each data packet. In satellite communication systems, [7], have proposed a scaling uplink power control algorithm for satellite systems working in the 30/20-GHz band [23]. The proposed algorithm makes use of 20 GHz attenuation scaled to 30 GHz to adjust the transmitted power at 30 GHz. The drawback of this scheme is that the dynamic range of power control is limited to approximately 10-12 dB. Another adaptive transmission power control scheme using a multi-beam satellite antenna is presented in [9]. In this scheme, the transmission power of the transmitter from the satellite towards the targeted site is controlled according to the attenuation at the reference sites. This scheme is only suitable for communication systems where the distance between sites is small; if the distance is large, this scheme produces little performance improvement. Although there are some other solutions for satellite transmission with power control techniques proposed by Wang, none of them have provided more insights into high quality video transmission over satellite links [25].

II UPLINK POWER CONTROL

The uplink power control (UPC) approach for dynamic allocation of additional power to the transmit carrier(s) at an earth station is used in order to compensate for rain attenuation. Uplink power control is one of the fade mitigation techniques that can be implemented easily. Power control at an earth station attempts to maintain a constant power flux density at the satellite irrespective of fading conditions along the propagation path [9].

Three types of uplink power control techniques to be considered are:

(1) Open Loop

(2) Closed loop

(3) Feedback loop

Open-loop**:** One station receives its own transmit carrier and must rely on its measurement of beacon fading in the downlink in order to perform uplink power control (UPC). Open loop is the easiest to implement and does not require system-wide considerations. It requires estimation of fading/enhancement on the up-link. One of the following methods may be used:

(i) Radiometry

(ii) Beacon measurement

(iii) BER measurement

Technique used determines accuracy and cost. In general, beacon measurement provides a higher accuracy at a modest cost.

(a) Beacon Measurements: In addition to propagation phenomena, beacon level variations are brought about by the following:

(i) Beacon effective isotropic radiated power (EIRP) changes

(ii) Instability of measurement system
(iii) Antenna pointing errors
(iv) Spacecraft maneuvers
(v) Modulation on beacon signal

Fade detection based is on establishing a clear-sky level that has a dominant diurnal pattern.

b. Closed-loop: Two earth stations are in the same beam coverage and an earth station can receive its own transmit carrier. UPC based on this carrier is erroneous due to changes in input and output back offs under uplink and downlinks fading. UPC needs to be on the reception of a distinct carrier transmitted from another station.

c. Feedback loop: A central control station monitors the levels of all carriers it receives, and commands the affected earth stations to adjust their uplink powers accordingly. This technique has inherent control delays, and requires more earth segment and space segment resources.

Downlink Power Control: This technique allocates additional power to the transmit carrier(s) at the satellite in order to compensate for rain attenuation. As the downlink fading occurs, downlink carrier power degrades and sky noise temperature seen by the earth station increases. Power control correction of approximately 1.5 times fade is required to maintain carrier to noise ratio (C/N). If correction is applied at the satellite, the effective isotropic radiated power (EIRP) for the entire beam is increased, raising the signal level at both faded and non-faded earth stations. For quasi-linear transponder operation, correction can be applied at the transmitting earth station. The Travelling wave tube amplifier (TWTA) with variable output power levels can be commanded into high-power modes to counteract downlink fades. For beam diameters greater that rain cell diameter, correction should be applied only when a certain percentage of terminals within the beam exceed an attenuation threshold. This technique must ensure that power flux density limits are not exceeded at non-faded terminals. The system design must ensure that the communication channel is not interrupted during power level changes [25].

Uplink Power Control - On-Board Processing Satellite: With an on-board processing spacecraft, for a link transmitting from point A and receiving at point B, the received information bit error rate at point B is given by:

$$BER_B = BER_{Uplink} + BER_{Downlink} \qquad (1)$$

where,

BER_{Uplink} = uplink information bit error rate = FU(BER Uplink)

$BER_{Downlink}$ = downlink information bit error rate = FD(BER Downlink)

FU (BER Uplink_) or FD (BER Downlink) = function describing relationship between uplink (or downlink) information BER and uplink (or downlink) channel BER.

The spacecraft need to monitor the levels of all carriers it receives in the uplink, and command the affected earth stations to adjust their uplink carrier powers accordingly [13].

To achieve the optimal transmission power consumption for specified link qualities, ATPC (Adaptive Transmission Power Control),is proposed. An adaptive transmission power control algorithm for wireless sensor networks to adjust the base station transmitted power in line with the climatic conditions. The result of applying ATPC is that every node knows the proper transmission power level to use for each of its neighbors, and every node maintains good link qualities with its neighbors by dynamically adjusting the transmission power through on-demand feedback packets [22]. Uniquely, ATPC adopts a feedback-based and pairwise transmission power control. By collecting the link quality history, ATPC builds a model for each neighbour of the node. This model represents an in-situ correlation between transmission power levels and link qualities. With such a model, ATPC tunes the transmission power according to monitored link quality changes. The changes of transmission power level reflect changes in the surrounding environment. ATPC supports packet-level transmission power control at runtime for media access control (MAC) and upper layer protocols. For example, routing protocols with transmission power as a metric can make use of ATPC by choosing the route with optimal power consumption to forward packets. Also, most existing satellite communication network systems use a network-level transmission power for each node. These coarse-level power controls lead to high energy consumption.

III EXPERIMENTAL SETUP

To investigate the spatial impact, we study the correlation between transmission power and link qualities in three different stations. We use one MICAz as the transmitter and a second MICAz as the receiver. They are put on the ground at different locations, maintaining the same antenna direction. The transmitter sends out 100 packets (20 packets per second) at each transmission power level. The receiver records the average Received Signal Strength Indication (RSSI), the average Link quality indicator (LQI), and the number of packets received at each transmission power level. The experiments are repeated with 5 different pairs of motes in the same environmental conditions to obtain statistical confidence.

Through our empirical experiments with the MICAz platform, it is observed that different transmission powers are needed to achieve the same link quality over time. This leads to a feedback-based transmission power control design. Also, the use of a fixed number of transmission powers, 13 levels, fixes the maximum accuracy for power tuning. The ATPC proposes different transmission power levels based on the dynamics of link quality, and it also allows for better tuning accuracy and more energy savings.

3.1 Model to implement Adaptive Transmit Power Control (ATPC)

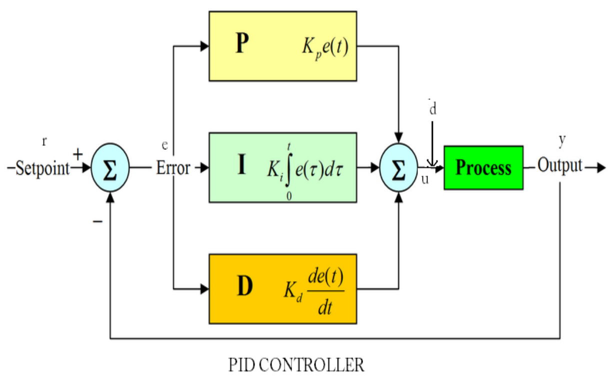

Figure 1: A block diagram showing Basic control system configuration for adaptive power control

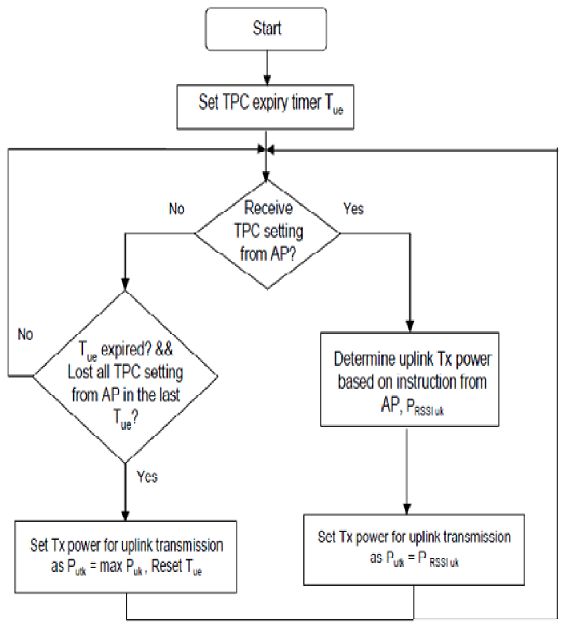

Figure 2:A flow Chart for STA TPC *Mode*1 operation

IV POWER CONTROL ALGORITHM

Video quality is largely dependent on IP packet loss, which in turn is determined by received signal strength. Therefore, in order to guarantee an acceptable video quality under different rainfall rate conditions, the transmit power has to be adjusted to compensate for losses. Conventional schemes like uplink power control or downlink power control are based on adjusting either the earth station transmitting power or satellite transponder gain. Those methods working alone suffer from latency caused by long round trip delay. Furthermore, the required compensation power or gain becomes a serious burden when either the satellite transponder or earth station is working alone under power control, which may easily push them to their power limits.

This work have combined uplink and downlink power control schemes to propose an adaptive closed loop power control algorithm with Proportional-Integral-Derivative (PID) controller. PID controllers have been widely adopted in systems with feedback to efficiently achieve stabilized state [6][27]. As weather conditions are always changing, a closed loop feedback power control system is needed to achieve the aforementioned compensation of the transmitting power. The benefit of a closed-loop power control approach is that it is able to adjust the transmission power adaptively according to current weather conditions in real time. In addition, a PID controller can help smoothen the feedback process, especially under drastic changes in rainfall rates. An adaptive power control mechanism should be designed to adjust both the satellite and earth station transmitting power in accordance to the commands generated by comparing the target and measured received signal level. Due to the contributions from both satellite and earth station, the loop is expected to react more quickly to the adjusting commands, which

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reduces the system stabilization time. Moreover, both satellite transponder and earth station share the responsibility to supply the required power compensation. Therefore, problems due to power limitation have been alleviated as well.

V NEED FOR ADAPTIVE TRANSMIT POWER CONTROL

From figure 3 below A station (STA) associates and communicates only with its nearest access point (AP). By minimizing the transmit power of the (AP) and its (STA) to a level that still ensures successful communication between them, the interference to other transmissions in the vicinity could be minimized.

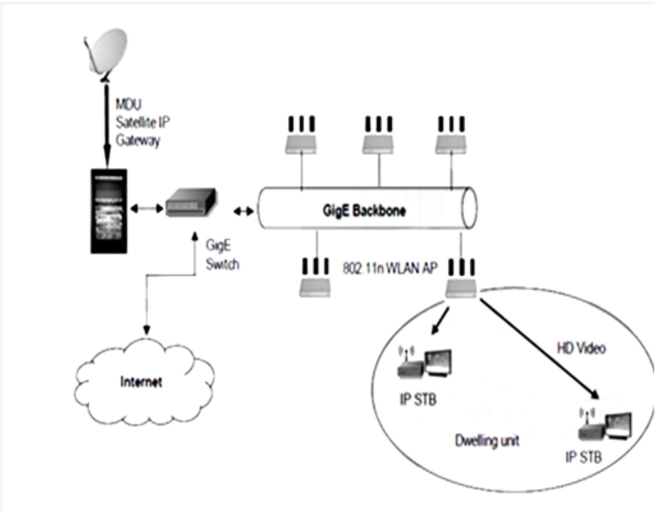

Figure 3: Typical Wireless Video Distribution System in a Multi-dwelling Unit

That is, other APs and its associated STAs at a certain distance can reuse the same channel without interference. This principle allows many AP-STA pairs to communicate at the same time in a given area while using only a limited number of wireless channels. The lesser the transmit power, the lesser the spatial interval needed to reuse the same channel without interference. This ensures an increase in the overall network capacity in a dense populated environment. For example, in cellular networks, smaller cell sizes with lower transmit power leads to the higher overall network capacity. The objective of Transmit Power control (TPC) on a wireless device (AP or STA) is to use minimum transmit power while meeting the requirements for throughput and packet loss rate. TPC helps reduce interference with other devices, improve channel reuse, and eventually increase the overall capacity in wireless networks. Of course, TPC also helps conserve energy and improve battery life of mobile devices. A transmitter can use lower power to transmit data when the receiver is close to it and still experience good channel conditions. However when the distance between the transmitter and receiver is relatively large and the channel condition is not good, the transmitter needs to use a higher power to transmit data in order to ensure that it is received correctly by the receiver and also to maintain the link throughput. The challenge is how a transmitter determines and adapts (if the channel condition changes) its transmit power to transmit data signal to a receiver optimally.

VI TPC DESIGN CONSIDERATIONS

TPC aims to use the minimum transmit power possible to achieve successful transmission at a target data rate. Since power control is done in a distributed manner certain undesirable side effects are inevitable. The design of an efficient TPC algorithm has to take those effects into account. TPC can exacerbate the classic hidden terminal problem and also introduce channel access asymmetry between two links operating on the same channel. The interaction between two transmitter (*Tx*) receiver (*Rx*) links can be summarized in the Figure 3.

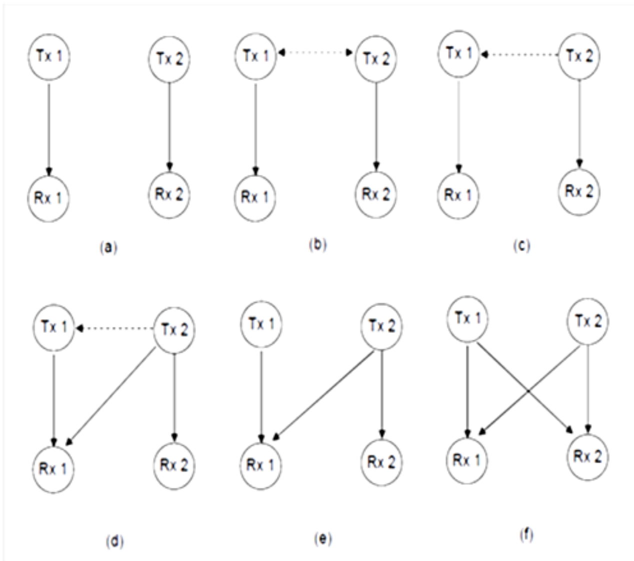

Figure 4: Scenarios that result from TPC

A solid arrow ($\longrightarrow$) from *Tx* to *Rx* indicates that the *Rx* is in the communication range of *Tx*. A dashed arrow ($\dashrightarrow$ from *Tx*2 to *Tx*1 indicates that *Tx*1 carrier can sense *Tx*2 . i.e., *Tx*1 can hear *Tx*2's transmissions). A detailed study of the frequency of occurrence of the six scenarios in unplanned dense deployments has been presented in [13]. When TPC is applied on a link it can result in any of the five scenarios presented in Figure 4. Scenario (*a*) represents the best case where, the application of TPC has resulted in complete spatial reuse. Scenario (*b*) represents no gain as far as spatial reuse is concerned but it is a wise choice to operate in the lowest possible transmits power if the target data rate can be sustained. Scenario (*b*) represents the exposed node problem that results in channel access asymmetry. *Tx*1 *Rx*1 link is starved since *Tx*2 cannot communicate with *Tx*1's transmissions and always perceives a clear channel. Scenario (*a*) also results in channel access asymmetry but the problem manifests itself in the form of packet losses at *Rx*1 due to simultaneous transmissions by *Tx*1 and *Tx*2. The transmitters are not in each other's carrier sensing range and hence this problem again manifests itself as packet losses at *Rx*1 or both *Rx*1 and *Rx*2 due to simultaneous transmissions.

VII NEED FOR TWO TRIGGERS

Most TPC solutions presented in most literatures fail to account for scenarios where you have more than one trigger (and power control has an increased tendency to result in such a scenario) since they rely entirely on only one trigger, either the Signal to Noise Ratio (SNR) deduced from Received Signal Strength Indicator (RSSI) measurements or Frame Loss Rate (FLR). If the power control solution is based on SNR, hidden terminal problem and asymmetric channel access problems cannot be diagnosed and there would be performance degradation due to frame losses. In such cases if the frame losses were monitored, an increase in transmit power to either leverage capture effect or to bring the interfering transmitter within the carrier sensing range would have a desirable effect. Solutions based on frame loss rate measurements alone are non-trivial as the minimum number of samples required to accurately deduce the channel conditions is a critical design choice and also they take a lot of time to converge. This work proposes an adaptive per-link TPC solution that precisely converges to the optimal transmit power based on Received Signal Strength Indicator (RSSI) and link margin measurements and also leverages Frame Loss Ratio (FLR) measurements to diagnose and remedy any adverse effects that TPC might have introduced. The need to quickly converge to the optimal power to operate at justifies the choice of RSSI measurements as the primary trigger. The desire to counteract the adverse effects that might have arisen due to power control as detailed earlier justifies the use of Frame Loss Ratio (FLR) as the secondary trigger. In Kishore Ramachandran, (2008), Symphony identifies exposed terminal problem through the use of a metric called Expected Transmission Time (ETT). Calculation of ETT and diagnosis of asymmetry in channel access is non-trivial since ETT calculation is complicated by variable packet size, queuing before transmission and packet aggregation in 802.11n [13].

VIII 802.11H MEASUREMENT FRAMEWORK

IEEE 802.11h is the amendment added to the IEEE 802.11 standard for spectrum and transmit power management extensions. It provides guidelines for TPC and Dynamic Frequency Selection (DFS) capabilities in IEEE 802.11 devices operating in the 5GHz spectrum (802.11a and 802.11n). There is a leverage the *TPC Request*, *TPC Report* and *Power constraint.* Information Elements (IE) which are part of 802.11h action frames to exchange link quality information (RSSI and/or link margin). In the solution the AP requests its associated STAs periodically to report their transmit power and downlink link margin information by sending a *802.11h TPC Request*. The *TPC request* is a 802.11h action frame that contains a *TPC request* IE as shown in Figure 5(a). After receiving a *TPC request*, the requested STA measures the received power of the transmissions from the AP and sends a *802.11h TPC report* to the AP. The TPC report is again a 802.11h action frame that contains a *TPC report* IE as shown in Figure 5(b)[10].

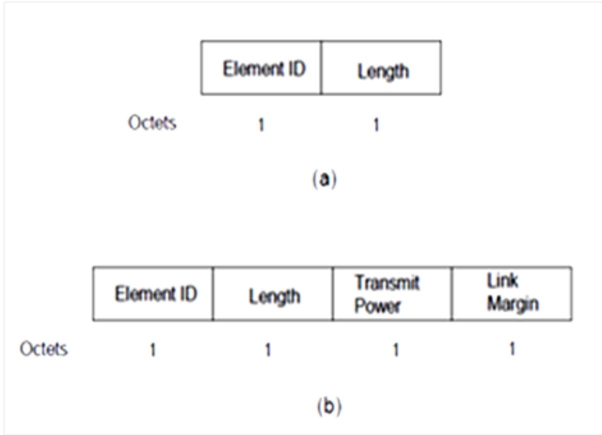

Figure 5 (a)TPC Request IE (b)TPC Report IE

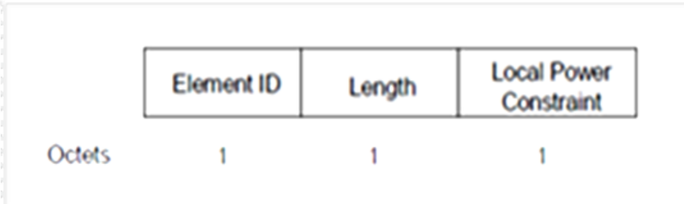

Figure 6: Power Constraint IE

The *TPC Report* element contains transmit power and link margin information sent in response to a *TPC Request* element. The transmit power field (3rd octet) shall be set to the transmit power used to transmit the frame containing the *TPC Report* element. The field is coded as a signed integer in units of decibels relative to 1mW (dBm). The link margin field (4th octet) contains the link margin at the time for the rate at which the frame containing the *TPC Request* element was received. The field is coded as a signed integer in units of dBm. The Link Margin is the received power minus the receiver sensitivity specified for the target data rate. After receiving a *TPC report*, the AP stores the information in its database for the purpose of power adaptation as described later.

The AP calculates the optimal transmit power for its transmission to each of the STAs. It also calculates the transmit power to be used by the each of the STA's for their transmission to the AP based on the link margin (received power of transmissions from the STA measured at the AP minus sensitivity for the target data rate) and transmit power conveyed by the *TPC Report* IE. This estimated transmit power is conveyed to the individual STAs by sending a management frame with the *Power constraint* IE carrying the optimal transmit power as shown in Fig.6 [10].

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IX RESULTS FOR ADAPTIVE POWER CONTROL

As well as the permitted time percentages and annual power boost times for ramp type ATPC system. For steps type systems, only single values (eg +6dB, +100dB) need be considered

Table I: Time permitted above the coordinated transmit power in an ATPC link

Power above Pt_{coord} (dB)	Permitted time (annual) %	seconds/ year
(≤) 0.0	100	31536000
(>) 0.0	0.50	157500
1	0.33	103950
2	0.22	69300
3	0.15	47250
4	0.10	31500
5	0.07	22050
6	0.047	14805
7	0.032	10080
8	0.021	6615
9	0.014	4410
10	0.010	3150

Table II: Average Rain rate with time in south Eastern Nigeria

TIME (ms)	RAINFALL RATE (mm/HR)
1000	0
2000	96
3000	96
4000	96
5000	96
6000	96
7000	0

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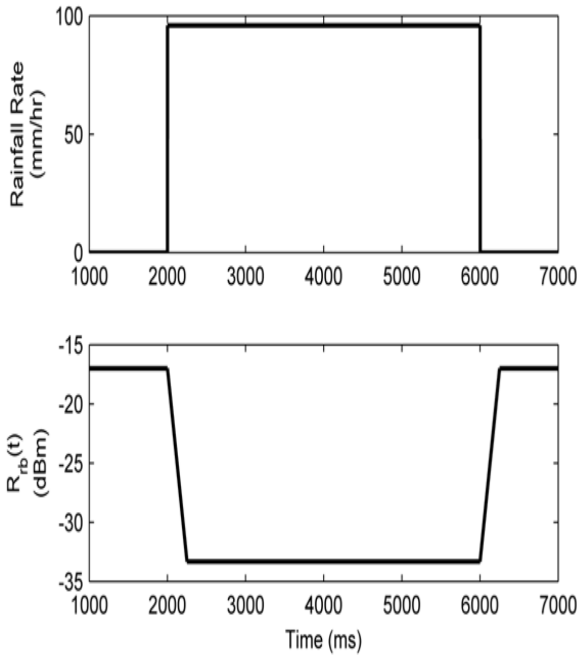

Figure 7. A plot of the system behaviour without power control in a rain event.

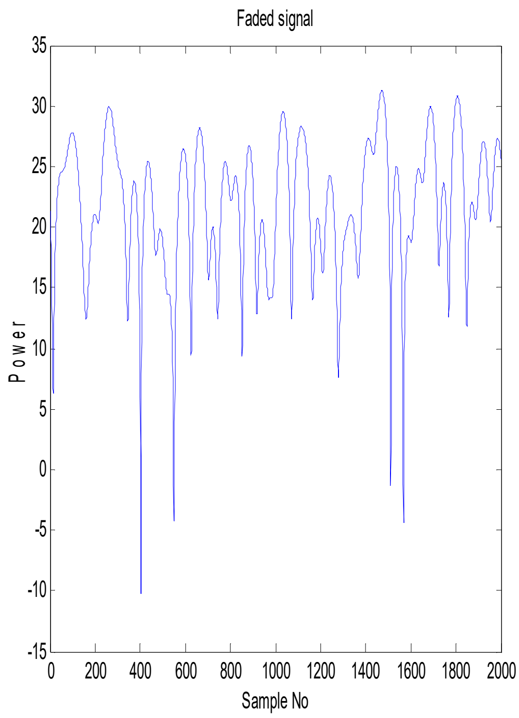

Figure 8. A simulation showing the fading effect of rain on signal power

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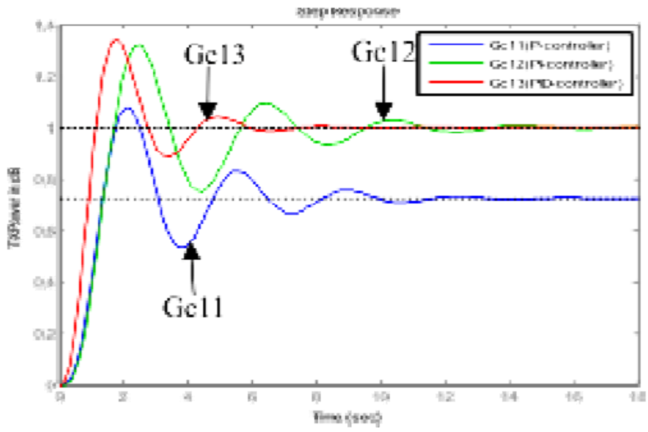

Figure 9. A simulation of a PID controller based on Ziegler-Nichols tuning rule to control attenuation as well as comparisons using Proportional (P) controller and Proportional Integral (PI) controller

A plot of a simple case with a pulse rain event without compensation is shown in Figure 7. As can be clearly seen, after the end of the rain event at 6000ms, the received signal power level gradually recovers to its normal level without abruptly changing state. This result resembles the real situation more closely. In order to further evaluate this scheme, the comparison of the system responses without power control implementation is presented in Figure 8. The rainfall rate is designed to increase gradually from 0 to 96 mm/hr which is the largest rainfall rate observed in the experimental records. The probability of rainfall rate exceeding 96 mm/hr is approximately 0.01% in one year, so 96 mm/hr effectively represents very heavy convective rain. The normal received signal level declines due to the rain attenuation. It is also demonstrated that the received signal level reduces as the rainfall rate continues to increase. Accordingly, the IP packet loss rate simultaneously goes up as a reaction to the decrease in received signal level. On the other hand, figure 9 shows a simulation using PID (proportional integral derivative) tuning using Ziegler-Nichol rules.

X CONCLUSION

Many scholars in the past has worked on power control in wireless networks but most of their proposed solutions either require changes to the MAC making them not incrementally deployable, or make unrealistic assumptions and ignore some limitations placed by the wireless card and device drivers rendering them not implementable in practice, or fail to address the hidden node and channel access asymmetry problems which manifest as frame losses that are exacerbated by TPC, while retaining the performance gains. In this work we propose an adaptive per-link transmit power control solution using a PID (proportional integral controller). PID has an enhanced response because it has shorter rising time, and setting time when compared with P and PI controller systems.

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