Adaptive Control of IoT Wireless Networks in Shadowed Fading Channels

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Abstract

In this paper, a distributed transmission power control (TPC) scheme that jointly addresses the hidden and exposed terminal problem to enhance the spatial reuse and fairness performance of multi-hop wireless networks is proposed. Unlike other previous transmission power control schemes where the two-ray ground reflection (TRG) model is adopted, the proposed scheme is designed based on a log-normal shadowing (LNS) channel model. In addition, transmission power selection strategies to further compensate the influences of shadowing are presented. Results demonstrate that the proposed scheme outperforms the other TPC schemes in terms of spatial reuse and power consumption, resulting in an improved throughput and energy efficiency.

Keywords: Transmission power control, Spatial reuse, Carrier sense multiple access with collision avoidance, Log-normal shadowing

1 Introduction

Accommodating simultaneous transmissions as much as possible is essential in multi-hop wireless networks to enhance the spatial reuse performance. However, in wireless networks employing carrier sense multiple access with collision avoidance (CSMCA/CA) including IEEE 802.11 distributed coordination function (DCF) and enhanced distributed channel access (EDCA) [1], hidden and exposed terminal problems restrain the overall system throughput and potential concurrent transmissions are inherently prohibited. In this context, transmission power control (TPC) schemes have been attracting a considerable research attention in order to enhance the spatial reuse performance.

More precisely, in CSMA/CA based multi-hop wireless networks, the hidden terminal problem arises when multiple transmissions from the nodes that are not aware of each others status (i.e., out of each others carrier sensing range) collides at the same receiver. The interference area is created with respect to a receiver, where transmissions within this area cause interference to the ongoing transmission. On the other hand, a node determines the channel to be busy if it senses an ongoing transmitted power level above a certain threshold (carrier sensing threshold). In other words, when the received power level is above the carrier sensing threshold, nodes can sense the ongoing transmission (by means of physical carrier sensing) and identifying the carrier sensing area.

There have been considerable research efforts to balance the interference and carrier sensing area (i.e., to balance the hidden and exposed terminal problems) [2-7]. The basic idea of TPC schemes is to differentiate the transmission power levels balancing the influence of the hidden and exposed terminal problems. For instance, the Request to send/Clear to Send (RTS/CTS) packets are transmitted with the maximum available power, whereas the DATA/ACK packets are transmitted with the minimum required power in [2]. Other schemes such as [3-4] use different criterions in selecting the transmission power level of DATA/ACK frames. A similar approach was also taken in [5], where a hybrid type method that combines rate and power control was used. However, since the works in [2-5] were built under the assumption of symmetric link conditions, the impact of asymmetry among links was considered in [6-7]. These two issues (i.e., differentiation of the transmission powers and asymmetry of links) were jointly considered in [8], where measured per-link interference levels were considered in power selection procedures. All of the papers mentioned above adopted the two-ray ground reflection (TRG) model, where it is assumed that there is a single line-of-sight path, and an additional ground reflected reception.

In this paper, a transmission power control scheme for the log-normal shadowing (LNS) channel is presented, considering the influence of asymmetric link conditions. The reference transmission power is derived and additional compensation strategies are introduced to further address the influence of

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shadowing.

The paper is organized as follows. In Section 2, the underlying channel and receiver model is presented, and the proposed TPC scheme is introduced in Section 3. The performance evaluations and comparisons are provided in Section 4. Finally, the related works and their impacts are introduced in Section 5, followed by the conclusion.

2 Related Works

There have been considerable research efforts to balance the hidden and exposed terminal problems, and these works can be classified into the following three categories: (1) transmission power and rate control schemes, which is the main scope of this paper, (2) tuning the carrier sensing ranges, and (3) link-level scheduling schemes to enhance the spatial reuse performance.

The transmission power control schemes, such as MTP [2], OTP [3], MCA [4], and the proposed TPC-LNS, regulate transmission power levels according to measured metrics, such as, received signal strength, distance, packet-error rate, etc. This approach is more practical compared to the others, since it can be used along with the legacy devices. However, the performance highly depends on the accuracy of measurements and estimations [8].

Another approach to address the hidden and exposed terminal problem is to tune the carrier sensing ranges (i.e., carrier sensing thresholds) as in [13-16]. To maximize the spatial reuse performance, the authors of [13] proposed a method to estimate an optimal carrier sensing threshold. The authors of [14] and [15] suggested carrier sensing range adaptation schemes, considering packet error rate and power consumption, respectively. However, as stated in [16], tuning the carrier sensing range results in a tradeoff between the number of packet collisions and spatial reuse performance. The shorter carrier sensing range can accommodate more simultaneous transmissions, but each transmitters becomes more vulnerable to the hidden terminal problem.

On the other hand, several link-level protocols were designed based on different approaches, such as an additional control period [17], differentiated handshaking [18], additional neighbor discovery phase [19], and conflict map based on empirical packet loss measurements [20-22]. These protocol designs and several other adaptive time and power control schemes [8], [23-26] can increase the spatial reuse performance, at the cost of memory, computational complexity, and incompatibility with the conventional CSMA/CA protocol.

3 System Model

3.1 Two-Ray Ground Reflection Model

The signal attenuation when propagating through the wireless channel is commonly modeled as a function of traveled distance. In the two-ray ground reflection model, when node *i* transmits to node *j* that is $d_{i,j}$ away with transmission power of $P_t(i; j)$, the received power at node *j* can be represented as in (1). In (1), G_t (G_r) and H_t (H_r) are the gain and height of the transmitting (receiving) antenna, respectively, λ is the wavelength, L is the system loss, and $D_{ref} = 4\pi\ H_tH_r/\lambda$. In the remaining of this paper, $d_{i,j}$ and $P_t(i; j)$ will be denoted as d and P_t, respectively, unless otherwise stated. More details about the two-ray ground reflection model can be found in [8-9].

$$P_r^{TRG}(d, P_t) = \begin{cases} P_t\left(\frac{G_tG_r}{L}\right)\left(\frac{\lambda}{4\pi d}\right)^2 & , d < D_{ref} \\ P_t\left(\frac{G_tG_r}{L}\right)\left(\frac{H_tH_r}{d^2}\right)^2 & , d \geq D_{ref} \end{cases} \quad \textbf{(1)}$$

3.2 Log-Normal Shadowing Model

In practical environments, the received signal strength between the two distinct locations usually experience different path losses due to surrounding environments even though the transmitter-receiver distances of the two locations are the same. Therefore, it is not deterministic as in the two-ray ground reflection model. Empirical measurements and analytical studies have shown that this behavior is random and log-normally distributed (normal in dB units) [9]. The path loss at distance d in the log-normal shadowing model (in dB) can be represented as in (2), where β is the path loss exponent, d_0 is the close-in reference distance, and $X_{\sigma_{\text{dB}}}$ is a random variable normally distributed with zero mean and standard deviation σ_{dB} (i.e., $X_{\sigma_{\text{dB}}} \sim N(0, \sigma_{\text{dB}})$). The path loss exponent β and the standard deviation σ_{dB} can be obtained from measured data and by applying linear regression techniques, minimizing the estimation errors in a mean square manner [9].

$$PL(d) = \overline{PL}(d) + X_{\sigma_{\text{dB}}} = \overline{PL}(d_0) + 10\beta\log\left(\frac{d_0}{d}\right) + X_{\sigma_{\text{dB}}} \quad \textbf{(2)}$$

Assuming $\sigma_{\text{dB}} = 0$ (i.e., there are no random shadowing component, also known as the log-distance path loss model), the received power at distance d can be represented as follows.

$$P_r^{LNS}(d, P_t, \sigma_{dB} = 0) = P_t\left(\frac{G_tG_r}{L}\right)\left(\frac{\lambda}{4\pi d_0}\right)^2\left(\frac{d_0}{d}\right)^{\beta} \quad \textbf{(3)}$$

In order to detect the ongoing transmission of other nodes (i.e., carrier sense), the received power level at a node must be greater than the carrier sensing threshold (ζ). Therefore, the maximum distance for successful carrier sensing can be obtained as in (4) based on (3). In addition, the maximum distance for successful reception (i.e., transmission range) $R_{TX}^{LNS}(P_t, \sigma = 0)$ can be obtained by replacing ζ in (4) with the receiver sensitivity υ.

$$R_{TX}^{LNS}(P_t, \sigma_{dB} = 0) = d_0 \sqrt{P_t \left(\frac{G_t G_r}{\zeta L}\right)\left(\frac{\lambda}{4\pi d_0}\right)^2} \quad \mathbf{(4)}$$

Since the received power level must be greater than υ for successful reception, the minimum transmission power to reach a given distance d can be obtained as follows, by equating (3) to υ.

$$P_{\min}(d) = \upsilon \left(\frac{L}{G_t G_r}\right)\left(\frac{4\pi d_0}{\lambda}\right)^2 \left(\frac{d}{d_0}\right)^\beta \quad \mathbf{(5)}$$

On the other hand, for a successful transmission and reception, signal to noise plus interference ratio (SINR) at the receiver must be greater than the SINR threshold (γ). Under a single-maximum power interferer assumption (i.e., there is only one interferer that transmits with maximum power $P_{\max}$), when a packet is transmitted with power P_t, the vulnerable interference range at the receiver can be represented as follows.

$$R_{IF}^{LNS}(d, P_t, \sigma_{\text{dB}} = 0) = d \sqrt[\beta]{\frac{\gamma P_{\max}}{P_t}} \quad \mathbf{(6)}$$

The comparison between the TRG and LNS models are provided in Figure 1. The path loss exponent was set to 2.0 and 3.0, and σ_{dB} = 3.0. The receiver sensitivity was υ = -64.4 dBm and the carrier sensing threshold ζ = -78.1 dBm, resulting in an approximate transmission range of 250 m and carrier sensing range of 550 m, respectively.

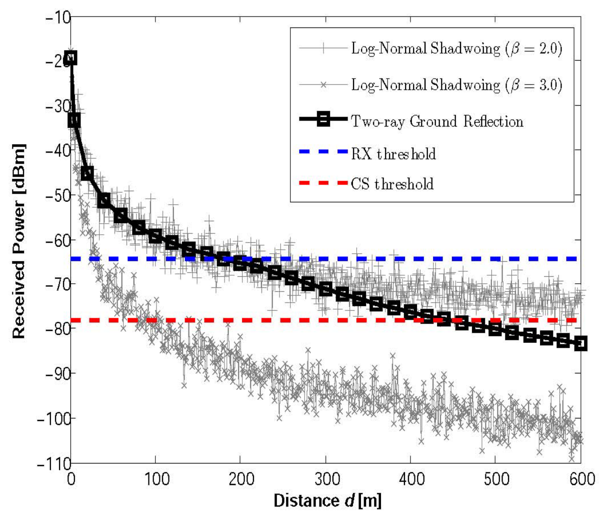


Figure 1. Comparison between TRG and LNS

4 Transmission Power Control

4.1 Transmission Power Selection

The procedures of the proposed TPC scheme can be summarized in the following three steps: (1) estimate the required information upon the reception of a packet, (2) obtain the reference transmission power, and (3) compensate the influences of the shadowing. In step (1), the information about the transmission power level and the average maximum interference level are included in the transmitted packets as proposed in [8]. The Distributed Transmission Power Control (DTPC) scheme in [8] differentiates transmission powers based on the measured interference levels of each link. This approach can be very useful since it relies on the actual amount of interference experienced, and therefore, can address the asymmetry of links appropriately.

The proposed TPC scheme for log-normal shadowing channels (i.e., TPC-LNS) works as follows. When node i transmits to j with power $P_t(i, j)$, the receiver j estimates the distance between j and i (i.e., $d_{j,i}$) using the transmission power level of node i based on (3). In addition, using the mean maximum interference level of i (i.e., $I_{\max}(i)$), node j assumes a single (hypothetical) representative interferer k that is at a distance $d_I(i)$ away from i. In other words, all interferers are aggregated and replaced with a single interferer at distance $d_I(i)$ that is transmitting with the maximum available transmission power $P_{\max}$. The distance $d_I(i)$ can be estimated as shown in (7) based on (3). These procedures (i.e., the estimation of $d_{j,i}$ and $d_I(i)$) are depicted in Figure 2.

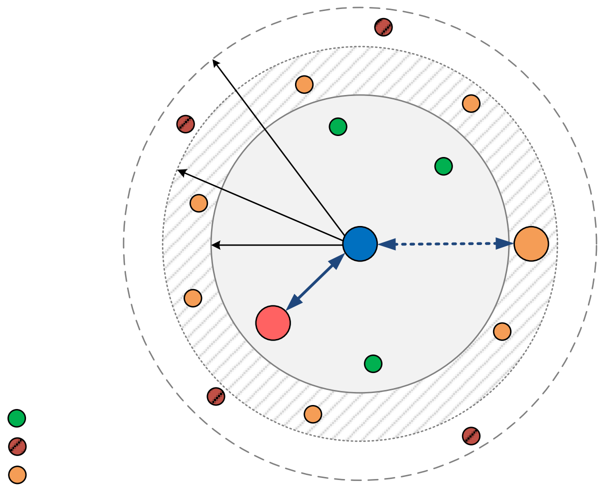


Figure 2. Reference power selection in TPC-LNS

$$d_I(i) = d_0 \sqrt[\beta]{\frac{P_{\max}}{I_{\max}(i)}\left(\frac{\lambda}{4\pi d_0}\right)^2 \left(\frac{d_0}{d}\right)^\beta} \quad \mathbf{(7)}$$

The reference transmission power of j is selected so that it can ensure a successful transmission over the representative interferer k. In other words, in Figure 2, the received power at node i upon node j's transmission should be sufficiently large so that the packet can be successfully decoded over the potential interferer located at $d_I(i)$ away from node i. This condition can be satisfied if $P_r(d_{j,i}, P_t(j, i))/I_{\max}(i) \geq \gamma$ and the corresponding transmission power of node j (i.e., $P_t(j, i)$) is controlled based on (8), which will be used as the reference power in the transmission power selection procedures.

$$P_{ref}(d_{j,i}, I_{\max}(i)) = \gamma I_{\max}(i)\left(\frac{L}{G_t G_r}\right)\left(\frac{4\pi d_0}{\lambda}\right)^2\left(\frac{d}{d_0}\right)^{\beta} \quad \textbf{(8)}$$

The reference transmission power of (8) is obtained under the assumption that there are no random shadowing influences (i.e., $\sigma_{\text{dB}} = 0$). Only 50% of signals will be received with enough power and the variation depends on σ_{dB}. Therefore, to account the shadowing influence, the following transmission power compensation strategies are taken. One simple intuitive strategy is to add $\alpha\sigma_{\text{dB}}$ to the reference transmission power as follows.

$$P'_{TPC-LNS} = P_{ref}(d_{j,i}, I_{\max}(i)) + \alpha\sigma_{\text{dB}} \quad \textbf{(9)}$$

According to the characteristics of a normal distribution, about 68% of the values lie within one standard deviation σ_{dB} away from the mean. In addition, approximately 95% and 99.7% are within two and three standard deviations, respectively (3-sigma rule) [10]. The transmission power in (9) may be sufficient to compensate the shadowing influences due to the negative random number generated from $X\sigma_{\text{dB}} \sim N(0, \sigma_{\text{dB}})$, but it may also assign an unnecessarily large transmission power when the number obtained from $X\sigma_{\text{dB}}$ is positive. The parameter α is a scaling parameter to control the amounts of compensations taken. Increasing α would result in a lower probability of having not enough reception power. However, this would also results in excessive transmission power, increasing the exposed terminal area and degrading the overall energy efficiency. In addition, since the resulting received signal strength with a negative numbered x obtained from $X\sigma_{\text{dB}}$ will likely be an unsuccessful transmission due to signal attenuation, it is natural and reasonable to add the amount of $|x|$ when x takes negative values. The absolute valued distribution of $X\sigma_{\text{dB}}$ (i.e., $Y = |X\sigma_{\text{dB}}| = |N(0, \sigma_{\text{dB}})|$) is called the half-normal distribution, and has the mean E[Y] = $\sigma_{\text{dB}}\sqrt{2/\pi}$ and variance Var[Y] = σ^2_{dB}(1-2/π). Based on this, the second strategy for transmission power compensation can be represented as follows.

$$P'_{TPC-LNS} = P_{ref}(d_{j,i}, I_{\max}(i)) + \alpha\sigma_{\text{dB}}\sqrt{2/\pi} \quad \textbf{(10)}$$

The last compensation strategy is the one proposed in [11], which can be represented as in (11), where y is a random variable drawn from $X\sigma_{\text{dB}} \sim N(0, \sigma_{\text{dB}})$.

$$P'_{TPC-LNS} = P_{ref}(d_{j,i}, I_{\max}(i)) + |y| \quad \textbf{(11)}$$

If the reference transmission power in (8) is 20.8 dBm and transmitted to the receiving node that is 100 m away (then, the received power at the receiving antenna is approximately -70.75 dBm), the probability density function (PDF) of the received power for the above mentioned compensation strategies are depicted in Figure 3, where σ_{dB} = 3.5. As can be seen from Figure 3, the compensated transmission power P_{ref} + $\alpha\sigma_{\text{dB}}$ is a more aggressive strategy than P_{ref} + $\alpha\sigma_{\text{dB}}\sqrt{2/\pi}$. Aggressive power compensation would result in a higher transmission power consumption. However, the throughput and spatial reuse not only depends on the transmission power, but also on the number of failures and retransmissions. The overall performance will be verified in the following section.

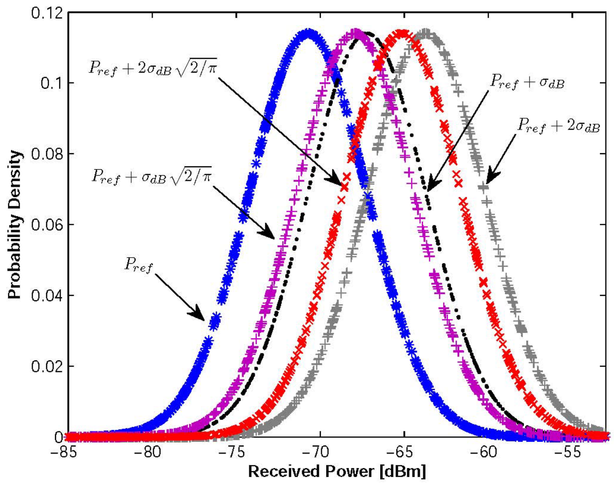


Figure 3. Probability density of received power

4.2 TPC-LNS Procedures

Based on the transmission power selection criterion explained in the previous subsection, the overall procedures of TPC-LNS can be summarized as follows.

- The RTS packet is transmitted with transmission power $P_{\max}$*. If it fails, then the transmission power of the RTS packet is tuned to the maximum available transmission power $P_{\max}$.
- Upon the reception of RTS packet, the receiving node selects the transmission power according to the following rule. Any kind of compensation strategies introduced in (8)-(10) above can be used in obtaining $P'_{TPC-LNS}$ based on the user preferences.

$$P_{TPC-LNS} = \max\left\{P_{\max}, \min\left\{P_{\min}\right\}, P'_{TPC-LNS}\right\} \quad \textbf{(12)}$$

The transmission power selection rule shown in (12) is obvious since the transmission power must be greater than the minimum required power level, and smaller than the maximum available power.

- The CTS packet is then transmitted based on the power level in (12). The transmission power of

DATA/ACK packets are tuned using the same procedures.

In summary, the proposed TPC-LNS operates in a fully distributed manner without the aid of centralized controller/scheduler, with a minimal level of information from the intended transmitter and/or receiver. In addition, since TPC-LNS relies on the measured interference levels of itself and the intended destination node, the asymmetry link conditions can be appropriately incorporated.

5 Performance Evaluation

Extensive simulations were conducted using an event-driven network simulator NS-2 [12] based on the scenario represented in Figure 4, which is a widely adapted scenario to verify the performance of TPC schemes. The system parameters used in modeling the IEEE 802.11b environment are listed in Table 1. The simulation results were compared in terms of average total throughput, average total transmission power consumption, and average energy efficiency with the conventional DCF [1], minimum transmission power (MTP) [2], optimal transmission power (OTP) [3], and minimum ceased area (MCA) [4] schemes. In addition, comparisons were made between P_{ref} (i.e., no compensation strategy is applied), $P_{\text{ref}} + \sigma_{\text{dB}}$, $P_{\text{ref}} + 2\sigma_{\text{dB}}$, $P_{\text{ref}} + 3\sigma_{\text{dB}}$, $P_{\text{ref}} + \sigma_{\text{dB}}\sqrt{2/\pi}$, $P_{\text{ref}} + 2\sigma_{\text{dB}}\sqrt{2/\pi}$, and $P_{\text{ref}} + |y|$, which are introduced in (7)-(11), respectively.

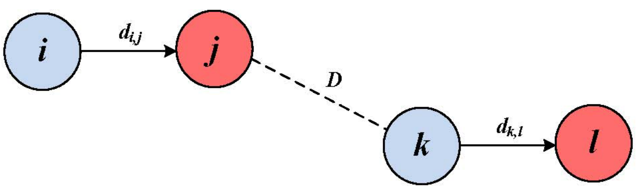


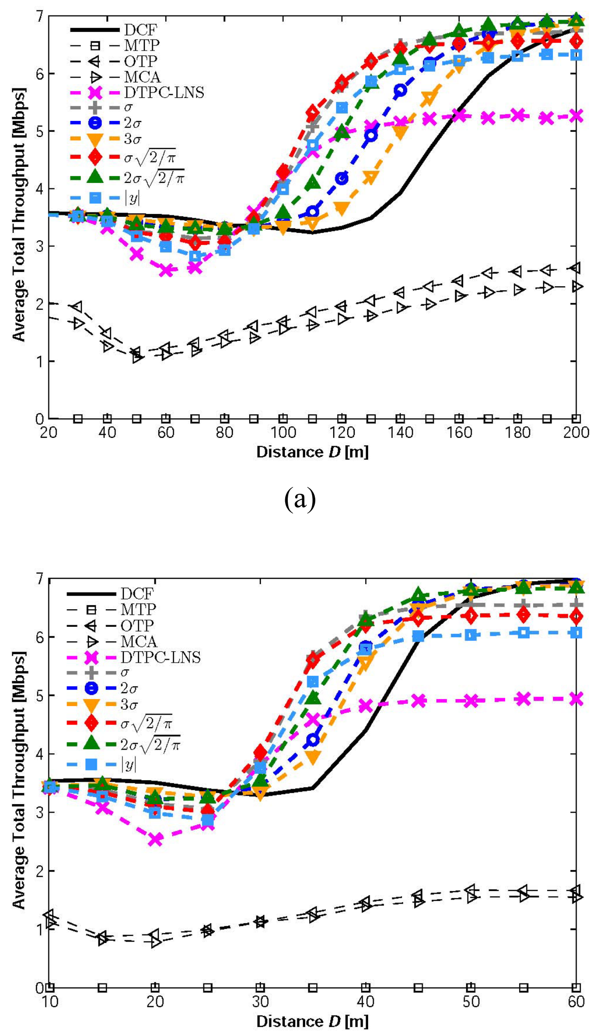
Figure 4. Target scenario

Table 1. System Parameters

$P_{\max}$	24.4 dBm	Payload	8000 bits
G_t (G_r)	1.0 (1.0)	PHY Header	24 bytes
L	1.0	MAC Header	28 bytes
λ	0.1244 m	Basic Rate	1 Mbps
γ	10 dB	Data Rate	11 Mbps
υ	-64.4 dBm	Slot Time	20 μs
ζ	-78.1 dBm	SIFS (DIFS)	10 (50) μs

5.1 Average Total Throughput

Figure 5(a) shows the average total throughput performance when $\beta = 3.0$, $\sigma_{\text{dB}} = 3.0$, where $d_{i,j} = 10$ m, and $d_{k,l} = 20$ m. The distance D between node j and k were varied from 10 to 200 m. In addition Figure 5(b) shows the average total throughput performance when $\beta = 4.0$, $\sigma_{\text{dB}} = 3.0$, where $d_{i,j} = 5$ m, and $d_{k,l} = 20$ m. The distance D between node j and k were varied from 10 to 60 m. It can be seen from Figure 5 that the other schemes that rely on the two-ray ground reflection model (i.e., MTP, OTP, and MCA schemes) do not work properly under the channel that experiences log-normal shadowing. Especially, the MTP assigns the minimum transmission power (calculated under the two-ray ground reflection model) in DATA/ACK packets. As a result, the received power is not sufficient at all to correctly receive the packet, resulting in complete starvation of both flows. The OTP and MCA schemes assign a little more transmission power to DATA/ACK packets and results in better performance compared to the MTP scheme, but the throughput is still undesirable over the entire range. For higher attenuation values, the throughput performance of MTP, OTP, and MCA severely decrease (close to zero).



(a)

(b)

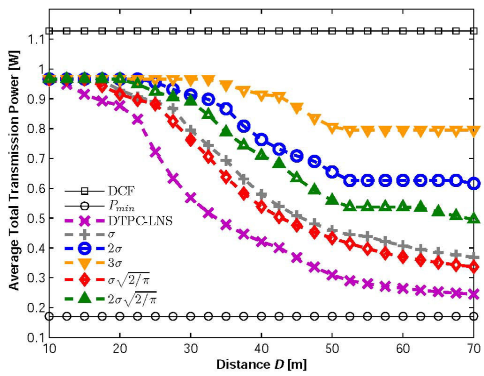
Figure 5. Average total throughput where (a) $\beta = 3.0$, $\sigma_{\text{dB}} = 3.0$ and (b) $\beta = 4.0$, $\sigma_{\text{dB}} = 3.0$

The throughput performance of TPC-LNS varies according to the compensation strategy used. When no compensation is applied (i.e., P_{ref}), the resulting throughput performance is relatively poor since it suffers from the influences of shadowing. This is due to the fact that throughput and spatial reuse not only depend on the transmission power, but also on the number of failures, collisions, and retransmissions. Comparing the two far-end strategies (i.e., $P_{\mathrm{ref}} + \sigma_{\mathrm{dB}}$ and $P_{\mathrm{ref}} + \sigma_{\mathrm{dB}}\sqrt{2/\pi}$), the throughput performance of $P_{\mathrm{ref}} + \sigma_{\mathrm{dB}}$ is slightly greater in relatively larger regions, but the opposite also holds in some regions (e.g., 50 ~ 150 [m] in Figure 5). Since $P_{\mathrm{ref}} + \sigma_{\mathrm{dB}}\sqrt{2/\pi}$ uses lesser transmission power, for the system with limited power requirements, it may be preferred to use $P_{\mathrm{ref}} + \sigma_{\mathrm{dB}}\sqrt{2/\pi}$, rather than $P_{\mathrm{ref}} + \sigma_{\mathrm{dB}}$, if the two perform similarly. As α in (9)-(10) increases and the transmission power converges to $P_{\max}$, getting closer to the performance of DCF. Since $2\sigma_{\mathrm{dB}}$ and $3\sigma_{\mathrm{dB}}$ covers more than 95% of the normal PDF, the received powers are more reliable in these cases. As mentioned earlier, the transmission power compensation strategy can be selected based on the user preferences.

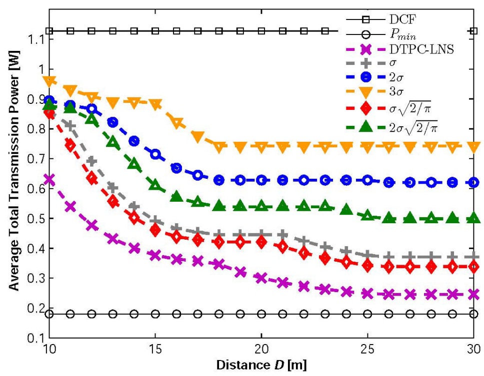
5.2 Average Total Transmission Power and Average Energy Efficiency

The average total transmission power consumption in Watts and energy efficiency in bits per Joule for various schemes are compared based on the same scenarios mentioned in the previous subsection. Figure 6 presents the average total transmission power spent to transmit all the RTS/CTS/DATA/ACK packets. Note that the conventional DCF assigns the maximum available transmission power (i.e., $P_{\max}$) for all of the RTS/CTS/DATA/ACK packets. Therefore, DCF can be considered as the scheme that uses maximum energy. It can be verified from Figure 6 that the proposed TPC-LNS consumes lesser transmission power compared to the conventional DCF scheme. Therefore, from the results shown in Figure 5 and Figure 6, it can be concluded that the energy efficiency (in terms of bits per Joule) of the proposed scheme is far better than the conventional DCF. Figure 7 shows the amount of bits transmitted per Joule of energy (i.e., energy efficiency).

Similar to the results observed in the throughput performance in the previous subsection, the two strategies $P_{\mathrm{ref}} + \alpha\,\sigma_{\mathrm{dB}}$ and $P_{\mathrm{ref}} + \alpha\,\sigma_{\mathrm{dB}}\sqrt{2/\pi}$ perform slightly differently based on the situations and surrounding environments. The choice of transmission power compensation strategies is up to the users based on their preferences and system requirements. When there are strict power limitations (light devices), it is preferred to use $P_{\mathrm{ref}} + \alpha\,\sigma_{\mathrm{dB}}\sqrt{2/\pi}$ rather than $P_{\mathrm{ref}} + \alpha\,\sigma_{\mathrm{dB}}$, and a smaller value of α. On the other hand, when the throughput and spatial reuse performance is more important than the overall power consumption (rich devices), then $P_{\mathrm{ref}} + \alpha\,\sigma_{\mathrm{dB}}$ is more preferable than $P_{\mathrm{ref}} + \alpha\,\sigma_{\mathrm{dB}}\sqrt{2/\pi}$. In this case, the α parameter should be appropriately selected, in order to balance the throughput (spatial reuse) and energy consumption

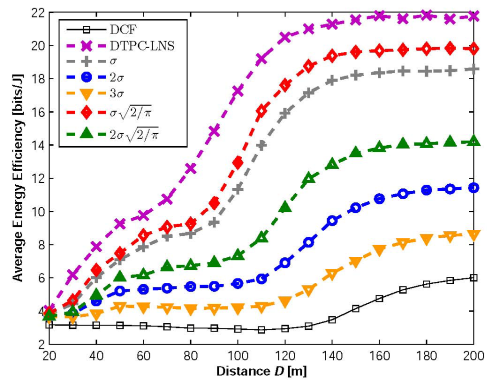


(a)

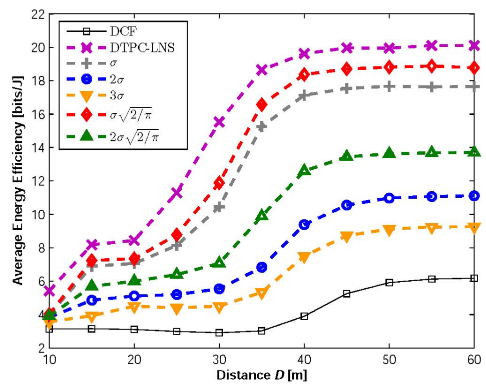


(b)

Figure 6. Average total transmission power where (a) $\beta = 3.0$, $\sigma_{\mathrm{dB}} = 3.0$ and (b) $\beta = 4.0$, $\sigma_{\mathrm{dB}} = 3.0$



(a)



(b)

Figure 7. Energy efficiency where (a) $\beta = 3.0$, $\sigma_{\mathrm{dB}} = 3.0$ and (b) $\beta = 4.0$, $\sigma_{\mathrm{dB}} = 3.0$

requirements for the given system and surrounding environments.

6 Conclusion

In this paper, a transmission power control scheme that can be applied in the log-normal shadowing channel environment is presented. At first, the reference transmission power was derived, and various transmission power compensation strategies were introduced to further handle the influence of shadowing. The proposed scheme operates in a fully distributed manner so that it can be compliant with the conventional CSMA/CA protocol. The results demonstrate that the proposed scheme is effective compared to the other transmission power control schemes that were built under the two-ray ground reflection model. The proposed scheme outperforms the other schemes in terms of average throughput, balancing the hidden and exposed terminal areas. In addition, the proposed scheme supports a lower power consumption compared to the other schemes improving the energy efficiency of communicating devices.

Future research needs to be conducted in the following directions. Practical experiments based on real-world data are required to further confirm the proposed scheme under various other channel conditions. Numerous variations in wireless channel states and their impacts on the proposed model will provide a more profound insight into the system and how this influences the overall performance. Based on this, the proposed model can be further optimized so that it can provide more accurate transmission power selection control.

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