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Interference Analysis at Mesh Access Point considering Mesh Node Activity

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***Abstract*-Wireless mesh networks have various link types around a mesh access point due to variety of network circumstances. Considering three different link types: star, ad hoc, and hybrid, we analyze the mean interference power at mesh AP according to link types. The effect of the mesh node activity on the mean interference power at mesh access point is also investigated. Through numerical results, it is observed that ad hoc link is highly dependent, star link is independent, and hybrid link is lightly dependent upon the pass loss exponent. In addition, it is shown that the mean interference power at MAP for the ad hoc link is always higher than that for the other links.**

Keywords: Mesh node activity, mean interference power, mesh access point, link type, and wireless mesh networks.

I. INTRODUCTION

Wireless mesh networks (WMNs) have emerged one of promising technologies for next-generation wireless networking. WMNs consist of two parts: a mesh access point (MAP) and a mesh node (MN). Both MAP and MN have the ability for mesh networking, i.e., handling many-to-many connections with dynamically updating and optimizing these connections to opportunistically use the best connection among them. Unlike the MN, MAP is equipped with a wired-connection to infrastructure/backbone enabling integration of WMNs with existing networks such as cellular networks, wireless local area network, wireless personal area network, wireless metropolitan area network, sensor networks, and so forth [1], [2].

Due to variety of network circumstances, there exist various link types around MAP. We consider three different link types: star, ad hoc, and hybrid as depicted in figure 1. The star link is fully centralized, like as a star topology, so that the MAP controls all MNs within its domain and each MN only communicates with the corresponding MAP, e.g., a typical piconet with one piconet coordinator and several slave devices. On the other hand, the ad hoc link is fully distributed, like as a peer-to-peer topology, so that each MN communicates with either the corresponding MAP or other MNs, e.g., a peer-to-peer communication in ad hoc networks.

The hybrid link is partially centralized and partially distributed, like as the combination of the star link and the ad hoc link. In this case, MNs not located in the star link domain can not directly communicate with the corresponding MAP. Their information should be relayed through the MNs located in the star link domain in order to be delivered to the corresponding MAP. In other words, the multi-hop transmission is required to deliver data from the MN to the corresponding MAP, e.g., a multi-hop infrastructure network architecture [3].

Even though each link type has its own advantage/ disadvantage, the amount of interference at MAP should be examined as a framework for evaluation of network performance. Note that mean interference power at MAP might be highly dependent upon link types. In this paper, we analyze mean interference powers at MAP according to link types and compare them according to the mesh node density, the mesh node activity, and the path loss exponent. The rest of this paper is organized as follows. In Section II, we describe the network model with three link types. In Section III, based on link types, we analyze the mean interference power at mesh AP. Numerical results are shown in Section IV, and conclusions are given in Section V.

II. NETWORK MODEL

As mentioned in the previous section, we consider a WMN with three different link types around the MAP: star, ad hoc, and hybrid. We assume the followings:

- MNs and MAPs are static and randomly distributed over a given area A.
- Each MN and MAP has an omni-directional transmit and

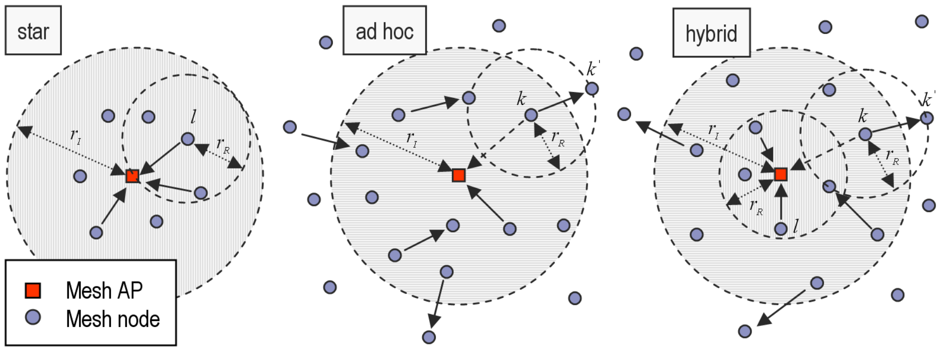

Figure 1 Link Types of WMNs (a) star link (b) ad hoc link (c) hybrid link

receive antenna of the same gain, and a bounded normalized maximum transmission power, P_T.

- Between transmitter *j* and receiver *k*, the channel gain is represented by $\gamma_{jk} = d_{jk}^{-\alpha}$, where d_{jk} is the distance between transmitter and receiver, and α is a path loss exponent.
- The received signal at each MN and the MAP is perfectly power-controlled so that it is equal to the lowest possible operational threshold, P_R, in order to guarantee a required quality-of-service (QoS).

As depicted in Figure 1, we define the maximum transmission range of each MN as r_R. Based on channel gain, r_R is determined by $\sqrt[\alpha]{P_T/P_R}$. For a source-destination MN pair, the transmission signal power at the source MN *j* is represented by $P_R \cdot \gamma_{jk}^{-1}$. The received interference signal power at the MAP due to the MN *k*, which is transmitting its information to its own destination MN k', can be calculated as $P_R \cdot \gamma_{kk'}^{-1} \cdot \gamma_{ks}$.

For the MAP, we define interference range of the MAP as r_I. According to channel gain, r_I is determined by $\sqrt[\alpha]{P_T/P_I}$ where P_I is a carrier sense threshold (CST). The CST is well known as the parameter that affects both interference level and spatial reuse [4]. Because *N* MNs are uniformly and randomly distributed over an area *A*, the probability that MAP has *n* interferers is modeled by two dimensional Poisson point process with a node density $\rho = N/a_I$ (where *N* is the number of MNs and $a_I = \pi r_I^2$ is the area covered by the interferers):

$$P[n \text{ interferers in the interference range}] \approx \frac{(\rho a_I)^n}{n!} e^{-\rho a_I} \quad (1)$$

Accordingly, the mean number of interferes is determined by $E[n] = \rho \pi r_I^2$. Note that the unit of ρ is m^{-2}.

The activity of the MN is one of important system parameters since it affects the amount of interference at the MAP. We assume homogeneous MNs which have the same statistical characteristic even though the locations of MNs are different. With this assumption, the activity of MN *j* (χ_j) can be modeled as the binomial distribution:

$$\chi_j = \begin{cases} 1, & \text{with probability } \varepsilon \\ 0, & \text{with probability } 1 - \varepsilon \end{cases} \quad (2)$$

III. MEAN INTERFERENCE POWER AT THE MAP

Under the star link (Figure 1.(a)), because all MNs are perfectly power-controlled at the MAP the received interference power at the MAP due to the node *l* is P_R which is deterministic value. Thus, the mean interference power at the MAP is easily obtained by

$$E[P_I^{st}] = E\left[\sum_{l=1}^{n} \chi_l P_R\right] = E[n] \cdot \varepsilon \cdot P_R \quad (3)$$

In case of the ad hoc link (Figure 1.(b)), the received interference power at the MAP due to the node *k* is the random variable represented as

$$P_{I,k}^{ad} = \chi_k \cdot P_R \left(\frac{d_{kk'}}{d_{ok}}\right)^{\alpha} = \chi_k \cdot U \quad (4)$$

$$\text{where } d_{ok} \in (0, r_I], \; d_{kk'} \in (0, r_R]$$

According to the received interference power at the MAP, we first derive the cumulative density function (CDF) of the random variable u using the method of event [5], [6].

$$F_U(u) = \begin{cases} \frac{1}{2}\left(\frac{r_I}{r_R}\right)^2 P_R^{-\frac{2}{\alpha}} u^{\frac{2}{\alpha}}, & 0 \le u < \frac{P_R r_R^{\alpha}}{r_I^{\alpha}} \\ 1 - \frac{1}{2}\left(\frac{r_R}{r_I}\right)^2 P_R^{\frac{2}{\alpha}} u^{\frac{2}{\alpha}}, & \frac{P_R r_R^{\alpha}}{r_I^{\alpha}} \le u < P_R r_R^{\alpha} \end{cases} \quad (5)$$

By differentiating (5), the probability density function is given by

$$f_U(u)=\begin{cases}\dfrac{1}{\alpha}\left(\dfrac{r_I}{r_R}\right)^2 P_R^{-\frac{2}{\alpha}}u^{\frac{2}{\alpha}-1}, & 0\le u<\dfrac{P_R r_R^\alpha}{r_I^\alpha}\\ \dfrac{1}{\alpha}\left(\dfrac{r_R}{r_I}\right)^2 P_R^{\frac{2}{\alpha}}u^{-\frac{2}{\alpha}-1}, & \dfrac{P_R r_R^\alpha}{r_I^\alpha}\le u<P_R r_R^\alpha\end{cases} \tag{6}$$

Now, let us consider the PDF of random variable $P_{I,k}^{ad} := w$. Since χ_k has the binomial distribution, w can be obtained as

$$f_W(w)=\varepsilon\, f_U(w)+(1-\varepsilon)\,\delta(w), \tag{7}$$

where $\delta(\cdot)$ is the Dirac delta function.

Using Equation (7), $E[P_{I,k}^{ad}]$ is obtained as

$$E[P_{I,k}^{ad}]=\varepsilon\left(\frac{P_R}{\alpha+2}\left(\frac{r_R}{r_I}\right)^2+\frac{P_R}{\alpha-2}\left(r_R^\alpha r_I^{-2}-r_R^\alpha r_I^{-\alpha}\right)\right) \tag{8}$$

Thus, we obtain the mean interference power at the MAP as

$$E[P_I^{ad}]=E\left[\sum_{k=1}^{n}P_{I,k}^{ad}\right]=E[n]\cdot E[P_{I,k}^{ad}] \tag{9}$$

For the hybrid link (Figure 1.(c)), there exist two kinds of received interference powers at the MAP. One is due to the node *l* from the star link and another is due to the node *k* from the ad hoc link. The received interference power at the MAP due to the node *k* is the random variable represented as

$$P_{I,k}^{hy}=\chi_k\cdot P_R\left(\frac{d_{kk'}}{d_{ok}}\right)^\alpha=\chi_k\cdot S \tag{10}$$

$$\text{where } d_{ok}\in(r_R,r_I],\ d_{kk'}\in(0,r_R]$$

It is noteworthy that the distance between the node *k* and the MAP is different from that of the ad hoc link.

Similarly to the ad hoc link case, the probability density function of the random variable s is derived by

$$f_S(s)=\begin{cases}\dfrac{1}{\alpha}\cdot\dfrac{r_I^2+r_R^2}{r_R^2}P_R^{-\frac{2}{\alpha}}s^{\frac{2}{\alpha}-1}, & 0\le s<\dfrac{P_R r_R^\alpha}{r_I^\alpha}\\ \dfrac{1}{\alpha}\cdot\dfrac{r_R^2-r_R^4/r_I^4}{r_I^2-r_R^2}P_R^{\frac{2}{\alpha}}s^{-\frac{2}{\alpha}-1}, & \dfrac{P_R r_R^\alpha}{r_I^\alpha}\le s<P_R\end{cases} \tag{11}$$

Now, let us consider the PDF of random variable $P_{I,k}^{hy} := v$. Since χ_k has the binomial distribution, v can be obtained as

$$f_V(v)=\varepsilon\, f_S(v)+(1-\varepsilon)\,\delta(v), \tag{12}$$

where $\delta(\cdot)$ is the Dirac delta function.

Using Equation (12), $E[P_{I,k}^{hy}]$ is obtained as

$$E[P_{I,k}^{hy}]=\varepsilon\left(\frac{P_R}{\alpha+2}\left(\frac{r_I^2+r_R^2}{r_R^2}\right)\left(\frac{r_R}{r_I}\right)^{\alpha+2}+\frac{P_R}{\alpha-2}\left(\frac{r_R^2-r_R^4/r_I^4}{r_I^2-r_R^2}\right)\left(1-\left(\frac{r_R}{r_I}\right)^{\alpha-2}\right)\right) \tag{13}$$

Finally, the mean interference power at the MAP is obtained by

$$\begin{aligned}E[P_I^{hy}]&=E\left[\sum_{l=1}^{n_s}\chi_l P_R+\sum_{k=1}^{n_a}P_{I,k}^{hy}\right]\\&=E[n_s]\cdot\varepsilon\cdot P_R+E[n_a]E[P_{I,k}^{hy}]\\&=E[n](\varepsilon\cdot P_R+E[P_{I,k}^{hy}])\end{aligned} \tag{14}$$

where $E[n_s]=\rho\pi r_R^2$ and $E[n_a]=\rho\pi(r_I^2-r_R^2)$ are the mean number of interferers from the star link and the ad hoc link, respectively.

Note that the mean interference power at the MAP for each link shows the different aspect. For the star link, the mean interference power at the MAP is not affected by the path loss exponent as shown in Equation (3). On the other hand, for the ad hoc link, the mean interference power at the MAP is fully affected by the node-to-node pair transmission around the MAP. Therefore, if the path loss exponent is high the transmission power generated by the node-to-node pair transmission will be high resulting in the increment of the interference power at the MAP.

IV. NUMERICAL RESULTS

Considering the mesh node activity and density, we evaluate the mean interference power at MAP based on three different link types: star, ad hoc, and hybrid. It is assumed that path loss exponents are 3, 4, and 5, the interference range of the MAP is 56m, the maximum transmission range of the MN is 25m, and the required received power threshold is -70dBm.

Figure 2 depicts the mean interference power at the MAP according to the mesh node density when the mesh node activity is 0.7. Given the same path loss exponent, the hybrid link shows the least mean interference power at the MAP. The amount of mean interference power at the MAP according to the path loss exponent also varied based on link types. From the figure, it is observed that the ad hoc link is highly dependent, the star link is independent, and the hybrid link is lightly dependent upon the pass loss exponent, respectively.

For three different mesh node densities, figure 3 shows the mean interference power at the MAP according to the mesh node activity where the path loss exponent is 4. Note that

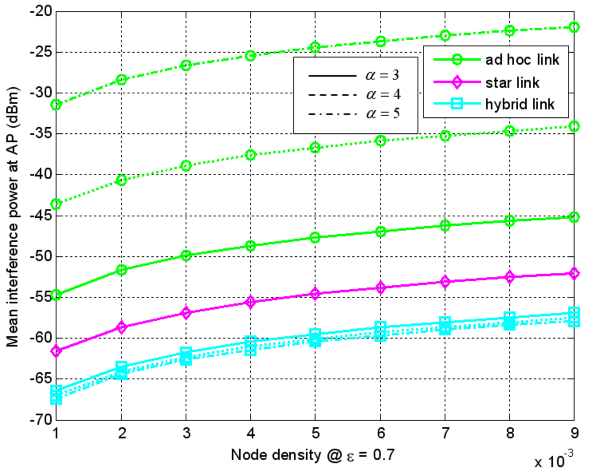

Figure 2 Mean interference power at the mesh AP according to mesh node density when $\varepsilon = 0.7$.

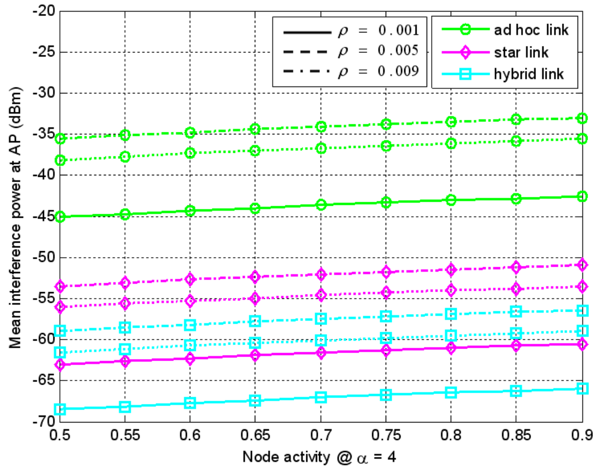

Figure 3 Mean interference power at the mesh AP according to mesh node density and mesh node activity when $\alpha = 4$.

based on requirement of mean interference power at MAP one can choose a proper link type to maintain a required QoS for WMNs. For example, in the figure, if a target mean interference power at MAP is -50 dBm only the star and hybrid link are possible to use.

Figure 4 demonstrates the three dimensional view of the mean interference power at the MAP according to both the mesh node activity and the mesh node density when the pass loss exponent is 4. It is shown that the mean interference power at MAP for the ad hoc link is always higher than that for the other links.

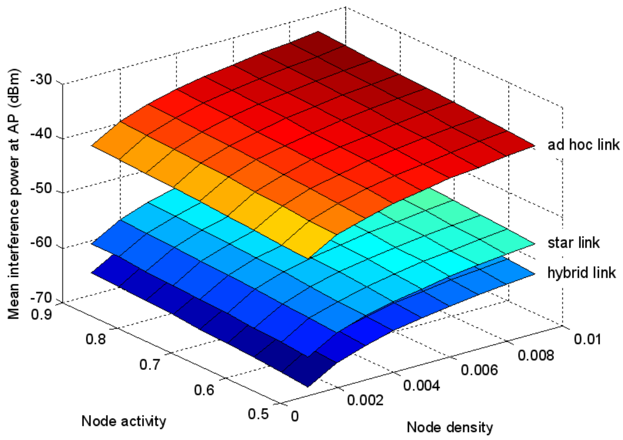

Figure 4 Mean interference power at the mesh AP according to mesh node density and mesh node activity when $\alpha = 4$.

V. CONCLUSIONS

In this paper, we analyzed the mean interference power at mesh AP based link types considering three different link types: star, ad hoc, and hybrid. In addition, the effect of the mesh node activity on the mean interference power at mesh access point is investigated. Through numerical results, we observed that three different link types have different characteristics in terms of mean interference power at mesh AP according to the mesh node density, the mesh node activity, and the path loss exponent. It is shown that ad hoc link is highly dependent, star link is independent, and hybrid link is lightly dependent upon the pass loss exponent. In addition, the mean interference power at MAP for the ad hoc link is always higher than that for the other links. Since the mean interference power at mesh AP is one of important performance metric that determine QoS of the networks, our results might be a framework for evaluation of network performance.

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