Location-based MAC Protocols for Mobile Wireless Networks

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***Abstract*— We consider medium access control (MAC) protocols for mobile ad hoc networks that are designed for MAC layer broadcasts. For example, such protocols could be used to transmit traffic information among vehicles. We analyze the performance of two simple MAC protocols, when multi-user interference is explicitly modeled via the received signal-to-interference plus noise ratio (SINR). One protocol is a simple slotted Aloha protocol with spatial reuse; the second protocol uses location information to determine the channel access. For both protocols we focus on a one dimensional model and measure performance in terms of the average number of nodes that receive each message in one hop.**

I. Introduction

In many ad hoc network scenarios it is desirable for nodes to broadcast information to all other nodes within their transmission range. Such so called MAC layer broadcasts can be used to share information with geographic significance. For example, in a vehicular ad hoc network (VANET), nodes may broadcast information to facilitate collision warnings [1], [2], cooperative (automated) driving [3], or advanced traveler information systems [4]. MAC layer broadcasts can also be used to disseminate network control information, such as routing tables or transmission schedules.

In this paper we consider the performance of two simple MAC layer broadcast protocols for a highly mobile ad hoc network. In this setting, there are two unique features that must be taken into account: (1) each transmission is not intended for a particular destination, but rather is to be broadcast to as many nodes as possible; (2) the network is highly mobile, limiting the amount of time two nodes maybe in range of each other. For example, because of these considerations using a RTS/CTS exchange as in IEEE 802.11 is not feasible. To limit the interference in this setting, we consider using a *location-based MAC protocol* as in [5]. With this protocol, mobile users exploit location information (e.g. available from GPS) to schedule their transmissions. Namely users only transmit when they drive through specific Transmission Areas (TAs); the location of these TAs are assumed to be stored in the on-board memory. Similar location-based MAC protocols have also been considered in [6]–[8].[1] We also consider a simple slotted Aloha protocol with spatial re-use under the common assumption that a signal is captured at a receiver when its SINR exceeds a given threshold (e.g. [9], [10]).

For the two MAC protocols, the main question we study is: what is the value (if any) of exploiting location information? We consider this for a model of a single (one-dimensional) road and measure the performance of the MAC protocols in terms of the expected number of receivers per message transmitted. In Section II, we describe this model in detail for both the slotted Aloha and location-based schemes. In Section III, we analyze the performance of the two schemes, and in Section IV, we present numerical results.

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[1]Compared to the protocol used here, the protocols in [6]–[8] use multiple channels; a user's channel varies with its position.

II. System model

We consider an ad hoc network in which the nodes are moving on an infinite length one-dimensional line. This can be viewed as a model of a single road, when the differences between lanes are ignored. All nodes know their location within a given tolerance. We assume that in steady-state the nodes are distributed according to a Poisson point process with parameter λ, so that the probability of n users in a length d interval is given by

$$p_d(n) = \frac{(\lambda d)^n}{n!}e^{-\lambda d}.$$

Each time a node transmits, we assume it transmits a fixed-size packet of L bits at a constant rate of r_0. All packets contain broadcast data, i.e., packets do not have a specific destination so no explicit routing is needed. For simplicity, we consider a slotted time model, where each time-slot's duration is the time required to send a packet, i.e., L/r_0. We assume that the time-scale of mobility is such that during each time-slot, the movement of a node is negligible.[2]

All transmissions are assumed to occur over a single channel. Under the MAC protocols described below, there will be multiple nodes transmitting in this channel within one time-slot. To determine if a given node receives a given transmission, we use the common SINR-based capture model as in [9], [10]. Specifically, the transmission is received correctly if and only if the receiver is not transmitting and

[2]As discussed below, we model only large-scale path-loss, so this assumption means that the path-loss does not appreciably change during a transmission.

the received SINR exceeds a given target β_t. This target is in turn determined by the transmission rate r_0 and the coding/modulation scheme that is used. For example, assuming a Gaussian noise channel with bandwidth W and optimal coding then $r_0 = W \log_2(1+\beta_t)$.[3] We also assume that $\beta_t \geq 1$ so that at most one transmission will satisfy the capture criterion at any given receiver (see e.g. [10]).

The received SINR at node j for a transmission from node i is given by

$$SINR_j(i) = \frac{P_r(d(i,j))}{\sigma_0^2 + \sum_{i' \in \mathcal{T} \setminus i} P_r(d(i',j))}, \quad (1)$$

where the $P_r(d(i,j))$ represents the received signal power at distance $d(i,j)$ from node i to j, σ_0^2 is the background noise power, and $\mathcal{T}$ denotes the set of nodes transmitting in the given time-slot. We focus on a simple attenuation model, in which there is no fading or shadowing, and thus the received signal power only depends on the path-loss. Specifically,

$$P_r(x) = P_{r0} \left(\frac{x}{x_0} \right)^{-\alpha}, \quad (2)$$

where α is the path-loss exponent (typically 2–4), and x_0 and P_{r0} are, respectively, the distance from the transmitter to a reference point and the associated received power.

A. Random access scheme

The basic random access scheme we consider is simply a slotted Aloha model with spatial re-use. In this protocol, in every time-slot, each user will independently decide to transmit or not with a fixed probability p_t. We focus on the performance of a single transmitter. We number this transmitter 0 and number the other nodes sequentially from left to right. For a given target SINR $\beta_t \geq 1$, based on our capture model, the following lemma is immediate:

Lemma 2.1: For $j > 0$, if user $j+1$ receives a packet from 0 successfully, so will user j.

Let j_{max} denote the furthest receiver to the right that receives a packet from 0, i.e.,

$$j_{max} = \sup\{j > 0 : SINR_j(0) > \beta_t\}. \quad (3)$$

We define the *progress* $\tilde{X}_r$ of this transmission to be the maximum distance a packet is propagated by this transmission, i.e. $\tilde{X}_r = d(0, j_{max})$.

Within a given time-slot, a user cannot transmit and receive data simultaneously. Hence, all of the nodes can be classified as either transmitters or receivers. Since each user transmits independently with probability p_t, it follows that the users' positions can be divided into two independent Poisson point processes corresponding to the transmitters and the receivers, with parameters $p_t\lambda$ and $(1-p_t)\lambda$ respectively. Given a particular realization of the position processes, we re-label the nodes depending on if they are a transmitter or a receiver. Specifically, we sequentially number the transmitters and receivers separately, so that receiver 0 is the first receiver to the left of transmitter 0. Let $\mathbf{Y} = \{Y_i\}_{i=-\infty}^{\infty}$ denote the positions of transmitters, and let $\mathbf{Y}' = \{Y_i'\}_{i=-\infty}^{\infty}$ denote the positions of the receivers, where all positions are measured relative to transmitter 0 (i.e. $Y_0 = 0$). Using this notation the progress of a transmission by transmitter 0, given the locations of all other nodes, is

$$\widetilde{X}_r(\mathbf{Y}', \mathbf{Y}) = Y'_{\arg\sup_j \{SINR_j(\mathbf{Y}', \mathbf{Y}) \geq \beta_t\}}, \quad (4)$$

where $SINR_j(\mathbf{Y}', \mathbf{Y}) = SINR_j(0)$ in (1) under the given realization of node locations. In other words,

$$SINR_j(\mathbf{Y}', \mathbf{Y}) = \frac{P_r(Y_j')}{\sigma_0^2 + I_j(\mathbf{Y}', \mathbf{Y})}, \quad (5)$$

where $I_j(\mathbf{Y}', \mathbf{Y}) = \sum_{i \neq 0} P_r(|Y_i - Y_j'|)$, is the received interference at receiver j.

Since the target SINR is assumed to be larger than 1, it is obvious that the furthest reachable receiver is located between the desired transmitter and the first interfering transmitter, *i.e.*, $0 < \widetilde{X}_r(\mathbf{Y}', \mathbf{Y}) < Y_1$.

In (4), the progress of a particular transmission depends on both the locations of the receivers and the transmitters. Next, we introduce a related quantity, the *virtual progress*, which does not depend on the location of the receivers. Specifically the virtual progress $X_r(\mathbf{Y})$ is the maximum distance x to the right a message could have propagated under any realization of the receivers. In other words, it is the maximum distance x with a SINR level exceeding β_t. Clearly, the virtual progress is an upper-bound on the progress. Given a realization of the transmitter positions $\mathbf{Y}$, the interference at position x, $I_x(\mathbf{Y}) = \sum_{i \neq 0} P_r(|Y_i - x|)$. The virtual progress is then given by

$$X_r(\mathbf{Y}) = \arg\sup_x \left\{ \frac{P_r(x)}{\sigma_0^2 + I_x(\mathbf{Y})} \geq \beta_t \right\}. \quad (6)$$

Taking the expectation over the positions yields the average virtual progress:

$$E(X_r) = E_{\mathbf{Y}}(X_r(\mathbf{Y})). \quad (7)$$

In the following we will use this as our main performance metric. Note that the average number of vehicles who receive a transmission on the right of the transmitter is then given by $\lambda E(X_r)$, and by symmetry the average number of vehicles on both sides who receive a transmission is $2\lambda E(X_r)$. In other words, looking at the average virtual progress is the same as looking at the average number of receivers.

For some applications, one might also be interested in the average progress[4], i.e., $E(\widetilde{X}_r) = E_{\{\mathbf{Y}', \mathbf{Y}\}}(\widetilde{X}_r(\mathbf{Y}', \mathbf{Y})),$. Using the Poisson assumption, this is related to the average virtual progress by

$$E(X_r) - E(\widetilde{X}_r) < \frac{1}{(1-p_t)\lambda}, \quad (8)$$

[3] Here, we are also making the common assumption that all interference can be modeled as Gaussian.

[4] For example, this is useful in studying multi-hop information propagation.

where the inequality is due to the probability that there is no receiver in this region. It follows that for high user densities, the difference between these two metrics is negligible.[5]

B. Location-based scheme

Next we turn to the location-based MAC protocol. The protocol we consider is based on the scheme presented in [5], in which transmission is allowed only in specific Transmission Areas (TAs).[6] In this protocol, we assume that the TAs are regularly spaced on the road, one every R meters. The region of radius $R/2$ around each transmission area is defined to be the *cell* associated with that TA. Figure 1 shows an example of one TA and its associated cell. We denote the length of a TA by r_g. Each node will attempt to send a packet with probability 1, whenever it is in a TA. For simplicity, we assume that a node is in a given TA for only one time-slot, i.e. $r_g/v \approx L/r_0$, where v is a nodes velocity. Furthermore, we assume that $r_g << R$, which is reasonable for the parameters in [5].

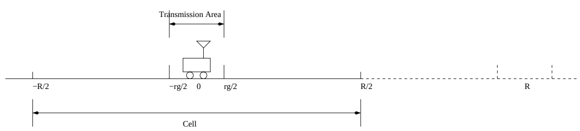

Fig. 1. An example of a TA and cell for the location-based protocol.

As with the Aloha-based scheme, we again focus on a given transmitter at position 0 and define the progress, $\widetilde{X}_f$, of the transmission to be the maximum distance to the right that the transmitted packet is propagated. Let the TAs be numbered sequentially, and without loss of generality assume the given transmitter is in TA 0. Define $\mathbf{Z} = \{Z_i\}_{i=-\infty}^{\infty}$ to be a sequence of Poisson random variables, where Z_i indicates the number of transmitters in ith TA. Again, let $\mathbf{Y}' = \{Y_i'\}$ denote the position of the receiving nodes.[7] The progress is then given by

$$\widetilde{X}_f(\mathbf{Y}', \mathbf{Z}) = Y_{\arg\sup_j \{SINR_j(\mathbf{Y}', \mathbf{Z}) \geq \beta_t\}}, \tag{9}$$

where

$$SINR_j(\mathbf{Y}', \mathbf{Z}) = \frac{P_r(Y_j')}{\sigma_0^2 + I_j(\mathbf{Y}', \mathbf{Z})}, \tag{10}$$

and

$$I_j(\mathbf{Y}', \mathbf{Z}) = \sum_{i=1}^{\infty} Z_{-i} P_r(iR + Y_j') + \sum_{i=0}^{\infty} Z_i P_r(iR - Y_j').$$

Here, we are assuming that r_g is negligible relative to R when calculating the distance between TAs. Notice that the progress may exceed R when no transmission occurs in the adjacent TA.

[5]The careful reader may note that the transmission probability would likely vary with the user density. However, under any reasonable scheme p_t will be decreasing with the density and thus the above argument still holds.

[6]In [5], several different location-based protocols were defined. Here, we focus on the "double-sided, one-channel protocol." The other protocols require that the transmitters use multiple orthogonal channels.

[7]Note that now $\mathbf{Y}'$ will not be a Poisson process.

The virtual progress, $X_f(\mathbf{Z})$, for the location-based scheme is given by

$$X_f(\mathbf{Z}) = \arg\sup_x \left\{ \frac{P_r(x)}{\sigma_0^2 + I_x(\mathbf{Z})} > \beta_t \right\},$$

where

$$I_x(\mathbf{Z}) = \sum_{i=1}^{\infty} Z_{-i} P_r(iR + x) + \sum_{i=1}^{\infty} Z_i P_r(iR - x).$$

Again, taking expectations yields the average virtual progress:

$$E(X_f) = E_{\mathbf{Z}}(X_f(\mathbf{Z})). \tag{11}$$

III. PERFORMANCE ANALYSIS

We compare the performance of the random-access and location-based schemes with the same target SINR, β_t and the same fraction of time during which each user transmits. From the above discussion, the fraction of time of each user transmits is p_t and $\frac{r_g}{R}$ for the random-access scheme and location-based scheme, respectively.[8] Thus, we set $p_t = \frac{r_g}{R}$. Recall that we are assuming $r_g << R$; hence, $p_t << 1$. This is reasonable for the random access scheme if the vehicle density is large enough.

We evaluate the performance of the two schemes using the expected virtual progresses, i.e., the quantities $E(X_r)$ and $E(X_f)$. We first bound these quantities and then use these bounds to compare the virtual progress between the schemes.

A. Bounds for the random access scheme

Notice that the virtual progress, X_r is a non-negative random variable and thus its expected value is given by integrating its complementary cumulative distribution functions (CCDF). We will bound $E(X_r)$ by first bounding the CCDF of X_r. Namely, we will give two other random variables, $\underline{X}_r$ and $\overline{X}_r$, so that $\underline{X}_r \leq_{ST} X_r \leq_{ST} \overline{X}_r$, where "$\leq_{ST}$" denotes the usual stochastic ordering.[9] Given such random variables, it follows that $E(\underline{X}_r) \leq E(X_r) \leq E(\overline{X}_r)$.

Let

$$SINR(x) := \frac{P_r(x)}{\sigma_0^2 + I_x}$$

denote the received SINR at position x, where I_x denotes the interference at position x (to simplify notation, we no longer indicate the dependence on the particular realization of transmitters). Given any $\beta \geq 0$, let

$$F_C^r(x, \beta) := \text{Prob}\{SINR(x) > \beta\} \tag{12}$$

be the CCDF of the SINR at distance x. Note that $SINR(x)$ is strictly decreasing in x and so $F_C^r(x, \beta)$ is also the CCDF of the virtual progress for a given SINR target of β, i.e., the

[8]Here, for the fraction of time a user transmits under the location-based scheme to be $\frac{r_g}{R}$, we need to make some assumptions about the mobility pattern, e.g. each user is moving in one direction with constant velocity.

[9]Two non-negative random variables X_1 and X_2 with CCDFs F_C^1 and F_C^2 satisfy $X_1 \leq_{ST} X_2$ if and only if $F_C^1(x) \leq F_C^2(x)$, for all $x \geq 0$.

CCDF of X_r is $F_C^r(x, \beta_t)$. Since the received power at a given location is deterministic, we have

$$F_C^r(x, \beta_t) = \text{Prob}\left\{I_x < \frac{P_r(x)}{\beta_t} - \sigma_0^2\right\}. \quad (13)$$

To upper bound $F_C^r(x, \beta_t)$, we consider the reachable distance when only the nearest interfering transmitters on both sides of x are present. Obviously, this results in a larger virtual progress than in the original random-access system, yielding the following bound.

Lemma 3.1: $X_r \leq_{ST} \overline{X}_r$, where $\overline{X}_r$ has CCDF $\overline{F}_C^r(x, \beta_t) = e^{-2p_t\lambda\beta_t^{\frac{1}{\alpha}}x}$. Furthermore,

$$E(X_r) \leq E(\overline{X}_r) = \frac{1}{(2p_t\lambda\beta_t^{\frac{1}{\alpha}})}.$$

Let $\mathcal{A}$ denote the event $\{I_x < \frac{P_r(x)}{\beta_t} - \sigma_0^2\}$, so that from (13), $F_C^r(x, \beta_t) = \text{Prob}(\mathcal{A})$. To lower bound $F_C^r(x, \beta_t)$, we consider a subset of $\mathcal{A}$ consisting of those realizations for which (*i*) there are no interfering transmitters within an interval $(x - y_0, x + y_0)$ and (*ii*) the interference from the transmitters outside the above interval is smaller than $\frac{P_r(x)}{\beta_t} - \sigma_0^2$. The probability of this subset lower bounds Prob($\mathcal{A}$). We further lower bound the probability of this subset using the Markov inequality. The resulting bound has the cleanest form when the noise power is negligible (i.e. $\sigma_0^2 \approx 0$), which we give in the following lemma. Of course if the noise power is not negligible, then dropping this term may no longer result in a lower bound.

Lemma 3.2: When the noise power is negligible, $X_r \geq_{ST} \underline{X_r}$, where $\underline{X_r}$ has the CCDF

$$\underline{F}_C^r(x, \beta_t) = \max\left\{e^{-2p_t\lambda\beta_t^{\frac{1}{\alpha}}x}\left(1 - \frac{2p_t\lambda\beta_t^{\frac{1}{\alpha}}}{\alpha - 1}x\right), 0\right\}.$$

Furthermore,

$$E(X_r) \geq E(\underline{X_r}) = \frac{1}{2p_t\lambda\beta_t^{\frac{1}{\alpha}}}\left(\frac{\alpha - 2}{\alpha - 1} + \frac{1}{\alpha - 1}e^{-(\alpha-1)}\right).$$

Note that $E(\underline{X_r})/E(\overline{X_r})$ is a constant depending only on α. For example, this means that as $\lambda \to \infty$, $E(X_r) = \Theta(1/\lambda)$.

B. Bounds for the location-based scheme

Next we turn to bounding the expected virtual progress in the location based scheme, $E(X_f)$. As we did for the random scheme, we bound $E(X_f)$ by first finding two other random variables, $\underline{X}_f$ and $\overline{X}_f$, such that $\underline{X}_f \leq_{ST} X_f \leq_{ST} \overline{X}_f$.

To upper bound X_f, for each location x we define a *critical disk* such that a transmission will not reach x if there are any interfering transmitters in this disk, even if all other nodes are idle. The probability a transmission reaches x, can then be lower bounded by calculating the probability that there are no transmitters except the desired one within this critical disk. Recall that in the location-based scheme, transmissions only occur in the TAs and number of users in any given TA is a Poisson random variable with mean λr_g. Using this yields the following bound:

Lemma 3.3: $X_f \leq_{ST} \overline{X}_f$, where $\overline{X}_f$ has CCDF

$$\overline{F}_C^f(x, \beta_t) = \frac{\lambda r_g e^{-\lambda r_g}}{1 - e^{-\lambda r_g}} \exp\left(-\lambda r_g \left\lfloor \frac{2\beta_t^{\frac{1}{\alpha}}x}{R} \right\rfloor\right).$$

Furthermore,

$$E(X_f) \leq E(\overline{X}_f) = \frac{\lambda r_g e^{-\lambda r_g}}{2(1 - e^{-\lambda r_g})^2\beta_t^{\frac{1}{\alpha}}}R.$$

We lower bound $E(X_f)$ by noting that conditioned on a successful transmission occurring, the one-hop progress of the location-based scheme is lower bounded by the one-hop progress of the random scheme. Here, by a "successful transmission" we mean that only one user is in TA 0. Multiplying our lower bound for the random scheme by the probability that a transmission is successful gives us the following bound. As in the random case, we state this bound assuming that the noise power is negligible.

Lemma 3.4: When the noise power is negligible, $X_f \geq_{ST} \underline{X}_f$, where $\underline{X}_f$ has CCDF

$$\underline{F}_C^f(x, \beta_t) = \frac{\lambda r_g e^{-\lambda r_g}}{1 - e^{-\lambda r_g}}\underline{F}_C^r(x, \beta_t).$$

Here, $\underline{F}_C^r(x, \beta_t)$ is the CCDF in Lemma 3.2 with $p_t = r/R$. Furthermore,

$$E(X_f) \geq E(\underline{X}_f) = \frac{e^{-\lambda r_g}}{2(1 - e^{-\lambda r_g})\beta_t^{\frac{1}{\alpha}}}\left(\frac{\alpha - 2}{\alpha - 1} + \frac{1}{\alpha - 1}e^{-(\alpha-1)}\right)R.$$

C. Performance Comparison

Using the bounds from the previous sections, we can now compare the performance of the two schemes. We focus on the case where the noise power is negligible.[10] Recall, we are assuming that $\frac{r_g}{R} = p_t$. Substituting this relation into the upper bound for the location-based scheme yields

$$E(\overline{X}_f) = \frac{(\lambda r_g)^2 e^{-\lambda r_g}}{(1 - e^{-\lambda r_g})^2}E(\overline{X}_r).$$

Likewise for the lower bound, we have

$$E(\underline{X}_f) = \frac{\lambda r_g e^{-\lambda r_g}}{1 - e^{-\lambda r_g}}E(\underline{X}_r).$$

Notice that both $\frac{(\lambda r_g)^2 e^{-\lambda r_g}}{(1-e^{-\lambda r_g})^2}$ and $\frac{\lambda r_g e^{-\lambda r_g}}{1-e^{-\lambda r_g}}$ are monotone decreasing functions of λr_g and always smaller than 1. Therefore, the upper and lower bounds for the location based scheme are always less than the upper and lower bounds for the random scheme, respectively.

Next, we consider the performance as $\lambda r_g \to 0$. In this limit the upper (lower) bound for $E(X_f)$ converges to the upper (lower) bound for $E(X_r)$. As noted above, the ratio between upper and lower bounds for $E(X_r)$ is a constant. Hence, the ratio between the upper and lower bounds for $E(X_f)$ is converging to a constant. When λ goes to 0,

[10] In the extreme case, when the noise power dominates the interference, it can be easily shown that the ratio of these two schemes should approach one.

assuming a fixed p_t, all the bounds increase without bound. We can conclude that the expected virtual progress for the two schemes both increase at the same order, namely $\Theta(1/\lambda)$ as $\lambda \to 0$. Summarizing, this we have:

Proposition 3.5:

1) For all choices of parameters, $E(\underline{X}_f) < E(\underline{X}_r)$ and $E(\overline{X}_f) < E(\overline{X}_r)$.
2) As λr_g goes to 0, $E(\underline{X}_f)/E(\underline{X}_r) \to 1$ and $E(\overline{X}_f)/E(\overline{X}_r) \to 1$.
3) As $\lambda \to 0$, with fixed p_t, all of the bounds grow like $\Theta(1/\lambda)$.

Suppose λr_g increases without bound. In this case, both $\frac{(\lambda r_g)^2 e^{-\lambda r_g}}{(1-e^{-\lambda r_g})^2}$ and $\frac{\lambda r_g e^{-\lambda r_g}}{1-e^{-\lambda r_g}}$ decrease to 0. It follows that for λr_g large enough the upper bound for the location-based scheme will be strictly less than the lower bound of the random scheme, and so $E(X_r) > E(X_f)$.

Proposition 3.6: Given any α, there exists a $D \geq 0$, such that if $\lambda r_g \geq D$, then $E(X_f) < E(X_r)$.

Note, when $\lambda r_g < D$, this does not imply that the location based scheme has a larger expected virtual progress.

IV. Simulation Results

We present some simulation results for both schemes. We simulate a large one-dimensional network in which the node locations are initially randomly generated according to a Poisson process. All the nodes then travel in the same direction with the same velocity. To avoid edge effects, we give performance results for nodes near the middle of the network. The results shown are averaged over 10^3 nodes and 10 simulation runs. All results are for the case where the noise power is negligible ($\sigma_0^2 = 0$).

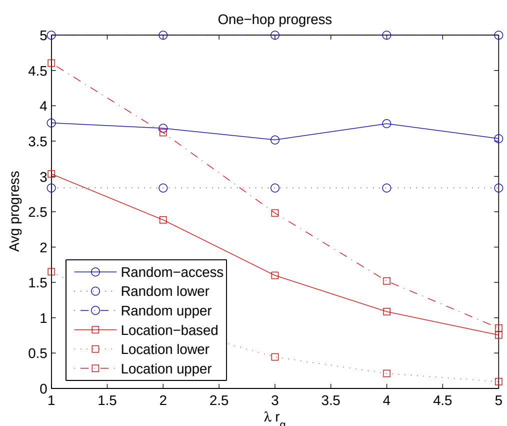

Fig. 2. Comparison of the two schemes with fixed $\lambda = 1$ and changing r_g.

In our simulations, we set $p_t = 0.1$, $\beta_t = 1$. In Figure 2, λ is fixed to 1 and r_g is varied from 1 to 5. We also vary R in order to keep $r_g/R = p_t$. It can be seen that the upper and lower bounds of the location-based scheme are always smaller than the corresponding bounds for random scheme. The bounds on X_f approach the corresponding bounds on X_r as λr_g decreases. This agrees with Proposition 3.5. Note

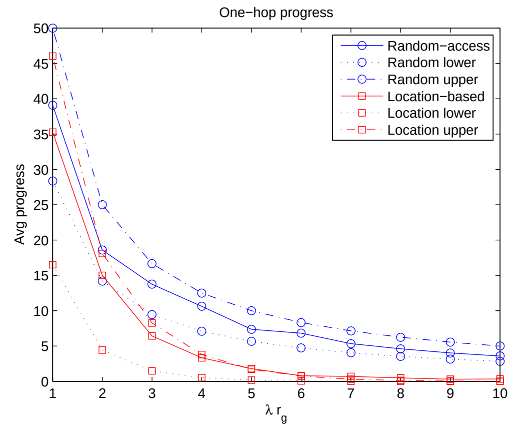

Fig. 3. Comparison of the two schemes with $r_g = 10$ and changing λ.

that the actual progress for the location-based scheme is also always less than that of the random scheme. In Figure 3, we fix r_g to be 10 and vary λ from 0.1 to 1. As predicted in Proposition 3.6, the upper bound of the location scheme eventually becomes smaller than the lower bound of random scheme for large enough values of λr_g.

V. Conclusion

We compared a location-based MAC scheme with a simple Aloha-based scheme in terms of the average number of receivers per transmission. Our analytic results show that for large enough user densities the Aloha-based scheme will perform better than the location-based scheme. Moreover, numerical results suggest that this is true for all user densities.

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