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TOWARDS REALISTIC MOBILITY MODELS FOR MOBILE AD HOC AND SENSOR NETWORKS

Summary. In this paper, we investigate the impact of mobility on the performance of multi-hop wireless ad hoc and sensor networks. We introduced some models of mobility in these networks and studied their behavior in realistic situations. It concerns the basic relationship between link length and message transmission. Additionally, we take into consideration the probability of successful transmission in an interference limited channel when fading is modeled as Rayleigh block fading. Our mobility models are verified by an accurate description and simulation of the behavior of mobile sensor and ad hoc networks.

Keywords: mobility models, mobile sensor networks, mobile ad hoc networks

REALISTYCZNE MODELE RUCHU DLA RUCHOMYCH SIECI AD HOC I SIECI SENSOROWYCH

Streszczenie. W pracy zbadano wpływ ruchu na wydajność wieloetapowych bezprzewodowych sieci ad hoc oraz sensorowych. Wprowadzono pewne modele ruchu w tych sieciach, a także zbadano ich zachowanie w realistycznych sytuacjach. Artykuł rozważa podstawowe zależności pomiędzy długością łącza radiowego a transmisją komunikatu. Rozważono w nim prawdopodobieństwo poprawnej transmisji w przypadku krótkookresowych zaników z funkcją gęstości prawdopodobieństwa obwiedni sygnału opisywanego rozkładem Rayleigha. Dla weryfikacji modeli ruchu przeprowadzono badania symulacyjne zachowania ruchomych sieci sensorowych i ad hoc.

Słowa kluczowe: modele ruchu, ruchome sieci sensorowe, ruchome sieci ad hoc

1. Introduction

An ad hoc network consists of nodes that may be mobile (Mobile ad hoc network, MANET) [1] and have wireless communications capability without the benefit of mediating infrastructure. Every node of an ad hoc network can become aware of the presence of other nodes within range. Communication links established in these networks do not rely on the use of an access point or base station. Data units are routed through the path from the origin to the destination.

Mobile sensor networks [2, 3, 4] are a paticular type of ad hoc network, in which the nodes are 'smart sensors'. They are equipped with sensing facilities, such as a pressure detector, a thermal indicator, an acoustic sensor, etc. In this type of network, the sensors exchange information on the environment and in this way build a global view of the monitored region.

It is obvious that in mobile ad hoc and sensor networks transmission depends on the assumed mobility model of the nodes in a network and the current condition of data transmission, such as channel fading, interference between nodes, etc.

In the case of mobile ad hoc networks were prepared mobility models [5, 6, 7]. In these models some characteristics of the nodes movements have been proposed. For example, in the Random Walk mobility model (equivalent to Brownian motion), nodes select a direction in which they will move between 0 and 2π, and speed from the given distribution.

In a random waypoint model [8], a node selects a destination in a random way and a distribution speed. Then, the node moves to the selected destination at the selected speed. Musolesi et al [9] used a social network theory to build a mobility model for an ad hoc network. This model allows collections of hosts to be grouped together based on the social relationship between the individuals. This grouping is then mapped onto a space, with movements influenced by the strength of social ties, which may also change over time. In the paper by Jardosh et al. [10] utilized obstacles to both restrict node movement and wireless transmission. Thus, the nodes can be randomly distributed across the paths.

The main goal of this paper is to introduce new mobility models. These models combine the direction and speed of the nodes with the basic parameters of wireless networks, such as the average *SINR* link, etc. Additionally, we considered how mobility acts on the link when this node is the beginning node.The proposed technique can be applied with some modifications in systems that support different types of movement in various conditions.

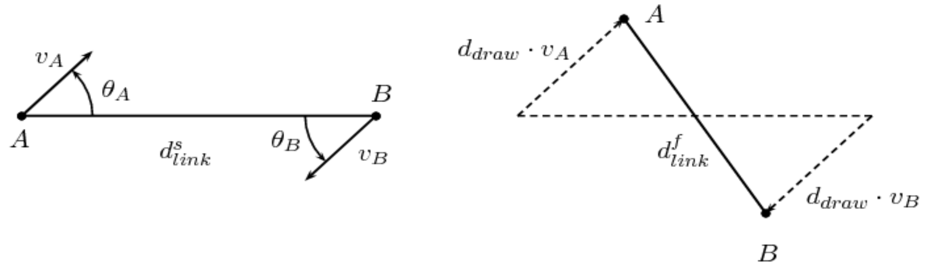
The paper is organized as follows. In Section 2 we provide mobility models with independent transmission over a link. In Section 3, we describe the Rayleigh fading link model of mobile ad hoc and sensor networks with independent transmission over a link. In Section 4 some numerical results are given. Finally, Section 5 concludes our study.

2. Mobility models with independent transmission over a link

2.1. Strategy without reservation

In this section, we present mobility models of mobile ad hoc wireless and mobile sensor networks with independent transmission over a link.In general, we can divide these models into these models without reservation and those with reservation [11].

We recall that in mobility models with independent transmission over a link without reservation, the position of a node can be treated as the final node. For instance, let two nodes be A and B and let the link between A and B be link AB (see Fig. 1).



a) $t = t_s$ b) $t = t_s + d_{draw}$

Fig. 1. An example of link evolution during message transmission in mobility model without reservation

Rys. 1. Przykład ewolucji łącza podczas transmisji komunikatu w modelu ruchu bez rezerwacji

We assume that these nodes have various speeds and angles of directions, denoted as (v_A, θ_A) and (v_B, θ_B), respectively.The start of transmission begins at the moment t_s and let the initial distance be $d^{(s)}_{link}$. The data transmission ends the moment $t_f = t_s + t_{trans}$. Thus, the final link of the transmission is given by

$$d^{(f)}_{link} = [d^{(s)}_{link}{}^2 + d^2_{draw}(v_A^2 + v_B^2) - 2v_A v_B d^2_{draw} \cdot \cos(\theta_A - \theta_B) + \\ 2 \cdot d_{link} \cdot d_{draw}(v_A \cos\theta_A - v_B \cos\theta_B)]^{1/2} \tag{1}$$

where d_{draw} is the distance travelled by a moving node between the starting and final position.

The average link length, $\overline{d}_{link}$, can be written as

$$\overline{d}_{link} = \frac{d^{(s)}_{link} + d^{(f)}_{link}}{2} = \frac{d^{(s)}_{link}}{2} + [d^2_{link} + d^2_{draw}(v_A + v_B^2) - 2v_A v_B d^2_{draw} \cos(\theta_A - \theta_B) + \\ 2d_{link} d^2_{draw}(v_A \cos\theta_A - v_B \cos\theta_B)]^{1/2} \tag{2}$$

Hence, the time that node B is in the transmitting range of node A, which is equal to the time during which the link between node A and B remains active, is

$$t_{link}=\frac{d_{link}}{|v|}=\frac{\overline{d}_{link}}{\sqrt{v_A\cdot\cos\theta_A-v_B\cdot\cos\theta_B}} \tag{3}$$

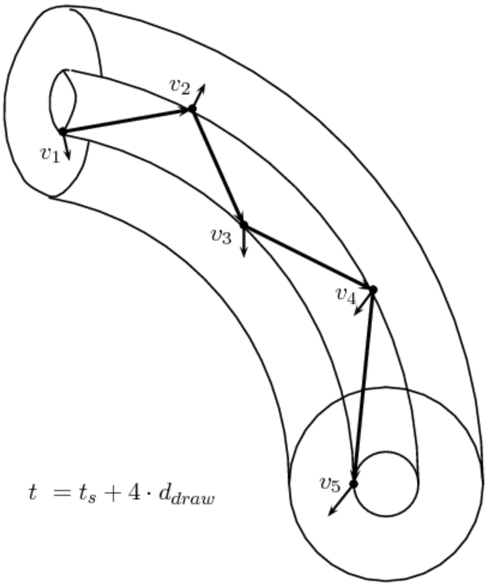


Fig. 2. An example of link evolution during message transmission in mobility model with reservation
Rys. 2. Przykład ewolucji łącza podczas transmisji komunikatu w modelu ruchu z rezerwacją łącza

2.2. Strategy with reservation

Multi-hop routing with reservation is characterized by the reservation of the links of the route. This strategy is used when the message does not reach the destination node of the route. Thus, the message transmission over the link is activated regardless of the corresponding link length. An example of a mobility model with reservation is given in Fig. 2. In the depicted situation "two tubes" are used as the communication route [12]. Inside the internal "tube", treated as the first "tube", messages are generated at the mobile source node and flow to the destination node. This "tube" belongs to the routing zone. The external "tube", defined as the second "tube", is the reservation zone, inside which the messages reserve the region by blocking it before causing an irruption of other mobile nodes. In other words, the first "tube" inside the second "tube" is most probably going to break and needs to be updated. The second "tube" is reserved as the security zone.

By using the approach given in the previous section, we obtain the starting and final link lengths, namely

$$d_{lin}^{(s)}=d_{link} \tag{4}$$

$$\begin{aligned} d_{link}^{(f)} &= [d_{link}^2+d_{draw}^2(v_1^2+v_2^2)-2v_1v_2d_{draw}^2\cos(\theta_1-\theta_2)+ \\ &\quad 2d_{link}d_{draw}(v_1\cos\theta_1-v_2\cos\theta_2]^{1/2} \end{aligned} \tag{5}$$

When we treat the link as the *i*-th route link between node n_i and n_{i+1} at the time $t = t_1 + (i-1)d_{draw}$, we can describe both the above dependencies as follows:

$$\begin{aligned} d_{link}^{(i,s)} = {} & [d_{link}^2 + [(i-1)d_{draw}]^2 (v_i^2 + v_{i+1}^2) - 2v_i v_{i+1} [(i-1)d_{draw}]^2 \cos(\theta_i - \theta_{i+1}) + \\ & 2d_{link} [(i-1)d_{draw} (v_i \cos\theta_i - v_{i+1}\cos\theta_{i+1})]]^{1/2} \end{aligned} \tag{6}$$

$$\begin{aligned} d_{link}^{(i,f)} = {} & [d_{link}^2 + (i \cdot d_{draw})^2 (v_i^2 + v_{i+1}^2) - 2v_i v_{i+1} (i \cdot d_{draw})^2 \cos(\theta_i - \theta_{i+1}) + \\ & 2d_{link} \cdot i \cdot d_{draw} (v_i \cos\theta_i - v_{i+1}\cos\theta_{i+1})]^{1/2} \end{aligned} \tag{7}$$

The average link length of link i is given by

$$\overline{d}_{link}^{(i)} = \frac{d_{link}^{(i,s)} + d_{link}^{(i,f)}}{2} \qquad i = 1,2,\ldots,N_i \tag{8}$$

where N_i is the maximum number of nodes over the *i*-th link. For the sake of simplicity, we assumed that the propagation time between two neighbouring nodes is negligible in comparison with the message transmission time.

2.3. The Rayleigh fading link model of mobile ad hoc and sensor networks with independent transmission over a link

In this subsection, we introduce the stochastic nature of the wireless channel to our mobility models of mobile ad hoc and sensor networks under the assumption of independent transmission over a link. Our analysis is based on Rayleigh fading channel model, which includes both large-scale path loss and stochastic small-scale variations in the characteristics.

We assume a Rayleigh block fading channel. A transmission from node A to node B is successful if the signal-to-noise-and-interference ratio (*SINR*) γ_{link} is above a certain threshold ϑ that is determined by the communication hardware, the modulation and coding scheme [13].The mean value of the distribution of the received power, $\overline{Q}$, is

$$\overline{Q} = P_t \left(\overline{d}_{link}\right)^{-\alpha} \tag{9}$$

where P_t is the transmit power. The $SINR_{link}$ in Rayleigh fading link model is given by

$$SINR_{link} = \frac{Q}{N_0 + I} \tag{10}$$

where Q is the received power, which is exponentially distributed with the mean $\overline{Q}$, N_0 is the noise power and I the interference power, that is the sum of the received power from all the undesired transmitters.

The conditional success probability of transmission over the link d_{link} between the node A and the node B of mobile ad hoc and sensor network with independent transmission over a link is given by

$$P_{dis\tan ce|d_{link},d_1,\ldots,d_n} = \exp\left(-\frac{\vartheta\cdot N_0}{P_t(\bar{d}_{linl})^{-\alpha}}\right)\cdot\coprod_{i=1}^{n}\left(1-\vartheta\cdot p\Big/\left(\left(\frac{d_i}{\bar{d}_{link}}\right)^{\alpha}+\vartheta\right)\right) \tag{11}$$

where P_t is the transmit power, p is the unconditional probability of transmission, N_0 denotes the noise power, α is the path loss exponent, ϑ is the *SINR* threshold, d_i $(i=1,\ldots,n)$ are distances from n potential interfering nodes.

Since the transmission in large ad hoc and sensor networks is limited by the interference, we focus on the second factor of (11). By applying $N_0 = 0$, it can be shown that

$$P_{dis\tan ce|d_{link},d_1,\ldots,d_n} = \coprod_{i=1}^{n}\left(1-p\Big/\left(1+\frac{r_i^{\alpha}}{\vartheta}\right)\right) \tag{12}$$

where $r_i = d_i/\bar{d}_{link}$ $\left(i=1,\ldots,n\right)$ are normalized distances.

3. Mobility models with dependent transmission over a link

In this situation, we divided the message duration into finite subintervals (slots) of the same size. If the propagation time is neglected, the distance covered by a mobile node is equal to $d_{draw}\cdot v/S$, where v is the speed of a mobile node, and S is the total number of subintervals. Assuming that the speed v of a mobile node is constant for the message transmission time, we admit a change in the movement angle. Thus, we obtain $\Delta\theta$ as the vector of particular angles of movement.

3.1. Mobility model essentials

For mobility models without route reservation we can give the average link length in the *i*-th subinterval as follows

$$\bar{d}^{(j)}_{link} = \frac{d^{(j,s)}_{link}+d^{(j,f)}_{link}}{2} \qquad j=1,2,\ldots,J \tag{13}$$

where J is the total number of subintervals.

Thus, the average link length during a message transmission is given by

$$\bar{d}_{link} = \frac{\sum_j^J \bar{d}^{(j)}_{link}}{2} \tag{14}$$

The vector of particular angles of movement for the starting node, n_A, is defined by

$$\Delta\bar{\theta}_A = (\Delta\theta_{A,1},\ldots,\Delta\theta_{A,J-1}) \tag{15}$$

Analogously, for the final node, n_B, the vector of particular angles is given by

$$\Delta\overline{\theta}_B = (\Delta\theta_{B,1},\ldots,\Delta\theta_{B,J-1}) \tag{16}$$

It is obvious that the average link length $\overline{d}_{link}$ depends on $(v_A,\theta_A,\Delta\overline{\theta}_A)$ and $(v_B,\theta_B,\Delta\overline{\theta}_B)$

In the reservation-based scheme of mobility models for consecutive links considered in relation to one another,we admit an extension of the scenario given in the previous section. The average link length $\overline{d}_i$ of the subinterval i depends on the elements i, namely $(v_i,\theta_i,\Delta\theta_i,v_{i+1},\theta_{i+1},\Delta\theta_{i+1})$. Thus, the vector $\Delta\theta_i$ for the subinterval is defined by

$$\Delta\theta_i = (\Delta\theta_{i,1},\ldots,\Delta\theta_{i,J-1},\ldots;\Delta\theta_{i,(i-1)(J-1))+1};\ldots;\Delta\theta_{i,i(J-1)}) \tag{17}$$

The realization of a single subinterval depends on the mobility achieved by a single node.

3.2. The Rayleigh fading link model of mobile ad hoc and sensor networks with dependent transmission over a link

Under the assumption of dependent transmission over a link, we underline that a node can change the direction of movement during a message transmission. Additionally, we suppose that all nodes are distributed according to a two-dimensional Poisson point process with density λ, the squared ordered distances from the desired receiver have the same distribution as the arrival times of a Poisson process with density $\lambda\pi$ [14].

The squared ordered distances have a joint distribution with density

$$f_{d_1^2,\ldots,d_N^2}(x_1,\ldots,x_n) = (\lambda\pi)^n e^{-\lambda\pi x_N} \tag{18}$$

because from [15] we have

$$f_{d_i^2-d_{i-1}^2}(x_i - x_{i-1}) = \lambda\pi e^{-\lambda\pi(x_i-x_{i-1})} \tag{19}$$

Thus, in a Rayleigh fading network the conditional success probability of transmission over a link with dependent transmission for fixed link can be written as

$$P_{dis\tan ce|d_{link},d_1,\ldots,d_N} = \coprod_{i=1}^{n} \frac{(d_i^2)^{\alpha/2} + (1-p)\vartheta\overline{d}_{link}^{\alpha}}{(d_i^2)^{\alpha/2} + \vartheta\overline{d}_{link}^{\alpha}} \tag{20}$$

where ϑ is the *SINR* threshold, d_i $(i = 1,\ldots,n)$ are distances from nodes to the desired receiver.

4. Numerical experiments

In this section, we study the impact of mobility on the performance of wireless sensor and ad hoc networks. We consider two mobility models, namely with links treated independently of one another and links that are not treated as independent of each other. In both cases, we evaluate the *SINR* for a link by means of the analytical approach proposed in previous sections. In all mobility models we used the random waypoint mobility model [6].

In the case of a mobility model with links that are treated independently of each other, we study two network scenarios, namely with route reservation and without reservation. We assumed the typical value of network communication. Our network consists of one thousand nodes with a spatial density equal to $10^{-6}[m^2]$. The average message length is 10 000 bits. The speed of a mobile node varies from zero up to 30 [m/s].

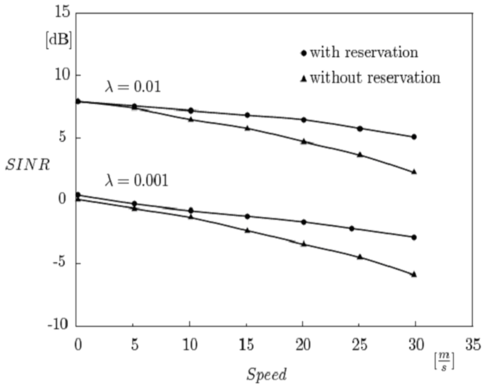


Fig. 3. *SINR* of a moving node as a function of the speed with independent transmission over a link

Rys. 3. *SINR* dla ruchomego węzła jako funkcja prędkości z niezależną transmisją w łączu

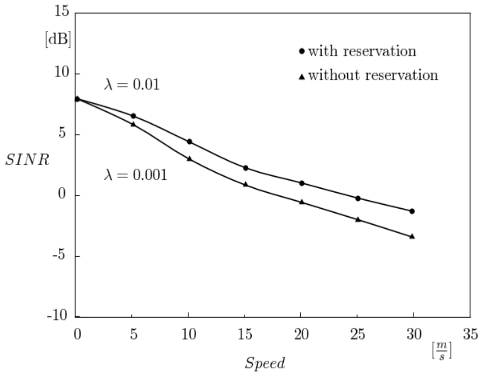


Fig. 4. *SINR* of a moving node as a function of the speed with dependent transmission over a link

Rys. 4. *SINR* dla ruchomego węzła jako funkcja prędkości z zależną transmisją w łączu

In Figure 3, the *SINR* for link is evaluated as a function of the speed. Two possible packet transmission rates are considered, namely $\lambda = 0.001$ and 0.01 [messages/s]. From the obtained graphs it is evident that a mobility model in which the direction of movement and route reservation changes performs better than a mobility model without reservation. It can be seen that the *SINR* in the case of a reservation scheme degrades rapidly as the node speed increases. This is caused by the fact that the links in the route reservation scheme can move slower than other links. Thus, the observed *SINR* is degraded.

In Fig. 4, the *SINR* for a mobility model with the status of a mobile node is dependent as its mobility status during the message transmission (in other words, the links are not independent of each other). We considered two cases: first, with route reservation, and second without reservation. We assumed that the maximum angle deviation in this case is equal to π. The results show that a scenario without reservation performs better than with route reservation.

5. Conclusions

Since mobility is a fundamental aspect of wireless ad hoc and sensor networks, the inclusion of mobility in the models is a crucial issue. In the basic mobility models that we presented in previous sections, mobility is not described in detail. Among other things, we made no distinction between the generation of a new call and the message transmission. However, our results shown that the use of mobility models with dependent transmission over a link performs better than mobility models with independent transmission over a link. Moreover, the use of mobile models for wireless ad hoc and sensor networks with route reservation does not ensure a better performance than networks without reservation. This is caused by the fact that frequent changes in movement force around their original positions than for away.

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Omówienie

Zagadnienie doboru modelu ruchu ma niezwykle duże znaczenie w przypadku wieloetapowych transmisji w ruchomych sieciach sensorowych i ad hoc. Dotyczy to w pierwszym rzędzie wpływu ruchu węzłów na czas trwania tworzenia połączeń w przypadku braku rezerwacji połączeń (rys. 1) oraz rezerwacji połączeń (rys. 2). Dodatkowymi problemami, które muszą być rozwiązane w trakcie tworzenia modelu ruchu dla tego rodzaju sieci, są zaniki sygnału. W pracy wprowadzono nowy model ruchu dla bezprzewodowych sieci sensorowych i ad hoc, w którym uwzględniono zależności pomiędzy długością łącza radiowego a transmisją komunikatu. Dopuszczono w nim zarówno jednoetapowe, jak i wieloetapowe transmisje. Wzięto w nim także pod uwagę poprawną oraz niepoprawną transmisję spowodowaną krótkookresowymi zanikami transmisji z funkcją gęstości prawdopodobieństwa obwiedni sygnału opisywanego rozkładem Rayleigha. W eksperymencie symulacyjnym wyznaczono zależność pomiędzy współczynnikiem SINR a średnią prędkością węzłów dla systemów z rezerwacją połączeń i bez rezerwacji połączeń z niezależną transmisją w łączu (rys. 3) oraz zależną transmisją w łączu (rys. 4).

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