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無線LAN環境におけるアトラクター選択を用いた経路選択手法

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経路選択問題は無線 LAN 環境における重要な問題の 1 つである．無線 LAN 環境における経路選択問題は，各無線端末が接続先アクセスポイントとアクセスポイントから目的端末までの有線経路を選択する問題である．本稿では無線 LAN 環境における，アトラクター選択を用いた経路選択手法を提案する．アトラクター選択とは生体系パラダイムに基づくアプローチの 1 つであり，現在の環境に対して適応的にシステムの状態を選択する能力を有する．アトラクター選択を適用することにより，提案手法は局所的な情報のみを用いて，高い通信スループットを実現するアクセスポイントと有線経路を適応的に選択する．また，提案手法の有効性をシミュレーションにより示す．

A wireless LAN network routing protocol based on attractor-selection

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With the spread of wireless LANs, routing in wireless LANs becomes important. Routing in wireless LANs is the problem that each wireless station selects access point and wired route to the destination station. In this paper, we propose an attractor-selection based routing protocol in wireless LANs. An attractor-selection is one of bio-inspired approaches and it can select good system states adaptively to the current environment. By applying the attractor-selection, our protocol can adaptively select access points and wired routes only using local information and attains high throughput. We show the effectiveness and adaptability of our protocol by simulations.

1 Introduction

Recently, wireless LANs which consist of access points (abbreviated by APs) and wireless stations (abbreviated by STAs), have widely spread. APs are connected by wired links with each other and STAs connect to APs by wireless links. Routing in wireless LANs is a problem that each STA selects one of APs to connect to and one of wired routes from the AP to its destination STA. This is a fundamental problem used in many applications, and thus, efficient routing protocols are required.

One of the difficulties in routing is to avoid the congestion of many communications. In general, when many STAs share the same AP, the throughput of the wireless link between the AP and each STA is degraded. Similarly, when many packets are sent through the same wired link, the throughput of the link is degraded. Thus, each STA should select an AP and a wired route appropriately in order to balance the load. The other difficulty is that each STA knows only local information. Each STA cannot get information about routes from APs unless it connects to them.

Our protocol is based on the attractor-selection, which is one of bio-inspired approaches. It is well known that bio-inspired approaches have high adaptability for dynamic environmental changes. The attractor-selection is the biological model first introduced by Kashiwagi et al [1]. The behavior of the attractor-selection is that, if the current state is not suitable for the current environment, the system changes its state randomly to search suitable states. If the current state becomes suitable for the current environment, the system becomes stable.

Leibnitz et al. proposed the attractor-selection based routing protocol in mobile ad hoc networks [2]. Leibnitz's protocol can select good route adaptively to the environment when all evaluation values of routes (ex. packet delays) are known. However, we cannnot apply Leibnitz's protocol to routing in wireless LANs since each STA cannot get information about routes from APs unless it connects to them.

Many protocols for AP selection[3, 4] and for wired route selection[5, 6] are proposed independently. We can realize routing in wireless LANs by applying both protocols at the same time, however, throughputs of communications might be low. For example, if a STA selects an AP with considering only throughputs of wireless links, throughputs of wired routes from the AP might be low. Thus, each STA should selects an AP with considering both throughputs of wireless links and throughputs of wired routes from APs.

In this paper, we propose a routing protocol that attains higher throughput by considering both AP selection and wired route selection. In our protocol, each STA evaluates its AP by the throughput of the wireless link and the throughput of the wired route from the AP. If one of the throughputs is low, the STA changes its AP until good APs are found. If the STA selects a good AP, the STA continues to select it. Thus, our protocol can select a good AP and a wired route. We show by simulations that our protocol adaptively selects APs and wired routes and attains high throughput.

2 Preliminaries

A system consists of STAs $S = \{s_1, \dots, s_{|S|}\}$, APs $A = \{a_1, \dots, a_{|A|}\}$ and a set L of bidirectional wired links each of which connects two distinct APs. AP a_i and AP a_j can communicate with each other directly only when link $e_{i,j}$ (or link $e_{j,i}$) is contained in L. We define a wired path from AP a_i to AP a_j as a sequence of wired links $r = \langle e_{i_0,i_1}, \ldots, e_{i_{k-2},i_{k-1}} \rangle$ such that $a_{i_0} = a_i$, $a_{i_{k-1}} = a_j$, and $e_{i_m,i_{m+1}} \in L$ $(0 \leq m \leq k-2)$. APs and STAs are deployed on a two dimensional plane. Each AP a_i has communication radius $c(a_i)$, and STA s_p can connect to a_i by a wireless link if distance from s_p to a_i is $c(a_i)$ or less. Then, s_p and a_i can communicate with each other directly. In this paper we assume that each STA can connect to at most one AP at the same time. Furthermore, we also assume that two STAs cannot communicate with each other directly. This implies that, when STA s_p sends packets to STA s_q, one or more APs have to relay the packets. That is, to realize such a communication, s_p connects to some AP a_i and selects a wired path from a_i to a_j, where a_j is the AP connected to by STA s_q.

Here, we define the throughput of communication from STA s_p to STA s_q. We assume that s_p and s_q connect to a_i and a_j respectively, and communicate via wired path $r = \langle e_{i_0,i_1}, \ldots, e_{i_{k-2},i_{k-1}} \rangle$ $(a_{i_0} = a_i$ and $a_{i_{k-1}} = a_j)$.

First, we define the throughput $\theta^{sa}_{p,i}$ of the wireless link between STA s_p and AP a_i. Let TA_i be the capacity of AP a_i that represents the maximum wireless throughput of AP a_i, NA_i be the number of STAs that connect to a_i, and $P_{p,i}$ be the packet error rate of the wireless link between s_p and a_i Then, $\theta^{sa}_{p,i}$ is defined as follows [3]:

$$\theta^{sa}_{p,i} = \frac{TA_i \times (1 - P_{p,i})}{NA_i + 1}.$$

Notice that, when many STAs connect to AP a_i, the throughput of wireless links between a_i and each STA is degraded.

Second, we define the throughput $\theta^{e}_{g,h}$ of wired link $e_{g,h}$. Let $TL_{g,h}$ be the capacity of link $e_{g,h}$ that represents the maximum wired throughput of link $e_{g,h}$ and $NL_{g,h}$ be the number of STAs that send packets through wired paths including $e_{g,h}$. Then, $\theta^{e}_{g,h} = TL_{g,h}/NL_{g,h}$. Notice that, when many STAs send packets through wired paths including $e_{g,h}$, the throughput $\theta^{e}_{g,h}$ is degraded. The throughput $\theta_{p,q}$ of communication from s_p to s_q is defined as $\theta_{p,q} = \min\{\theta^{sa}_{p,i}, \theta^{sa}_{q,j}, \theta^{e}_{i_m,i_{m+1}} | 0 \leq m \leq k-2\}$.

In this paper, we consider the problem such that each STA requests communication with its destination STA. We denote by $t(s_p)$ the destination STA of s_p. Our goal is to realize all communications requested by STAs and maximize the throughput of each communication.

In this paragraph, we define the available information of each STA. We assume that each station s_p knows all APs that it can connect to and the throughputs of wireless links to them. In addition, while each STA s_p connects to some AP a_i, s_p can get all wired paths from a_i to a_j and the throughputs of them, where a_j is the AP connected to by $t(s_p)$. Notice that each STA can connect at most one AP at the same time, and it does not know any information about wired paths from the other APs.

In the following sections, we concentrate on the behavior of each STA. That is, we propose a protocol that specifies which AP each STA connects to and which wired path each STA uses.

3 Our Protocol

Our protocol is based on two kinds of attractor-selections; one for AP selection and one for wired path selection. The outline of our protocol is as follows. First, STA s_p gets information of APs that s_p can connect to, and calculates the throughputs of wireless links of them. Then, s_p selects one AP a_i by the attractor-selection based on wireless throughputs. Next, each STA gets information of wired paths from a_i to AP a_j that STA $t(s_p)$ connects to, and selects one wired path r by the attractor-selection based on the throughputs of these wired paths. At this time, s_p selects a_i without considering throughput of wired paths from a_i. If throughput of the wired path from s_p to $t(s_p)$ is low, s_p selects another AP by the attractor-selection based on both throughput of wireless links of APs that s_p can connect to and throughput of r. Note that, $t(s_p)$ also selects a_j by its own attractor-selection independently.

3.1 AP selection

In this section, we explain how STA s_p selects its AP. In the following, we denote by a_c the AP that s_p connects to.

Selection manner We define $a_1, \ldots, a_{M_a}$ as the APs which s_p can connect to. Then, we consider $m^a_1, \ldots, m^a_{M_a}$ which correspond to the proportions that s_p selects $a_1, \ldots, a_{M_a}$, respectively. To adapt to the environmental changes, each STA periodically selects an AP with probability $m^a_i / \sum_{k=1}^{M_a} m^a_k$, and connects to the selected AP (i.e., a_c is changed into the selected AP). The dynamic behavior of each m^a_i is defined as follows:

$$\frac{dm^a_i}{dt} = \frac{\alpha \times (50\alpha^3 + 1/\sqrt{2})}{1 + (m^a_{max})^2 - (m^a_i)^2} - \alpha \times m^a_i + \eta_i, \qquad i = 1, \ldots, M_a \tag{1}$$

where m^a_{max} is the maximum value among all m^a_i and η_i is the white Gaussian noise. We denote by a_{max} the AP a_i such that $m^a_i = m^a_{max}$. The variable α is called activity and it reflects the goodness of a_{max} for the current environment. When a_{max} is good, α becomes close to 1, and when a_{max} is not good, α becomes close to 0. We explain α in detail later. Eqn.(1) is based on the atractor selection and is the same as [2]. From Eqn.(1), m^a_{max} converges to H-value $(50\alpha^3 + 1/\sqrt{2})$ and others converge to L-value $(1/2)\left[\sqrt{4 + (50\alpha^3 + 1/\sqrt{2})^2} - (50\alpha^3 + 1/\sqrt{2})\right]$. Thus, s_p selects a_{max} with high probability and rarely selects other APs. Notice that, when α becomes closer to 0, the dynamic behavior of m_i is strongly dominated by random term η_i and the difference of H-value and L-value becomes smaller. Therefore, s_p randomly changes a_{max} and all APs are selected with uniform probability. On the other hand, when α becomes closer to 1, the dynamic behavior of m_i is less dominated by random term η_i and the difference of H-value and L-value becomes larger. Therefore, a_{max} becomes stable and the system selects a_{max} with higher probability.

Behavior of activity We define the activity to reflect the goodness of AP a_{max}. The best AP for STA s_p is one that maximizes the throughput from s_p to its destination STA $t(s_p)$. However, s_p cannot recognize the best AP since s_p only knows the throughput to $t(s_p)$ via a_c and throughput of wireless links between s_p and other APs. Thus, only when a_{max} and a_c are the same, s_p can reflect the throughput of the wired path from a_{max} to the activity. Thus, we change the behavior of the activity in AP selection according to whether a_{max} and a_c are the same or not.

First, for the case that a_{max} and a_c are the same, we define the dynamic behavior of the activity α as follows:

$$\frac{d\alpha}{dt} = 0.1 \times \left(\left(\frac{l_{s_p,t(s_p)}}{l^a_{max}} \right)^{\frac{6}{k}} - \alpha \right), \qquad (2)$$

where l^a_{max} is the maximum wireless throughput among all APs that s_p can connect to and $l_{s_p,t(s_p)}$ is the current throughput of the communication between s_p and $t(s_p)$. The value k changes sensitiveness of α to the difference between $l_{s_p,t(s_p)}$ and l^a_{max}. If s_p frequently changes its AP, it suspects that throughputs of all wired paths are much lower than that of wireless links. Then s_p increments k by one. If s_p continues to connect to the same AP over a certain period, it recognizes that the throughput of wired links and wireless links get closer to each other. Then s_p decrements k by one while $k > 0$. In this paper, we adjust $k = 2$ as the initial value. From Eqn.(2), α converges to $\left(l_{s_p,t(s_p)}/l^a_{max}\right)^{\frac{6}{k}}$. Therefore, when s_p connects to a_c with high wireless throughput and communicate via a wired path with high throughput, α becomes close to 1.

Next, for the case that a_{max} and a_c are different, we define the dynamic behavior of the activity α as follows:

$$\frac{d\alpha}{dt} = 0.1 \times \left(\left(\frac{l^a_{a_{max}}}{l^a_{max}} \right)^{\frac{6}{k}} - \alpha \right), \qquad (3)$$

where $l^a_{a_{max}}$ is the throughput of wireless link between s_p and a_{max}. From Eqn.(3), when a_{max} is different from a_c, the dynamic behavior of the activity α depends on only the throughput of the wireless link between s_p and a_{max}.

3.2 Wired path selection

In this section, we explain how STA s_p selects a wired path after connecting to some AP. We assume s_p and $t(s_p)$ connect to AP a_c and AP a_d, respectively, and communicate via wired path r_v.

Selection manner Similar to the AP selection, s_p gets the information of all wired paths (denoted by $r_1, \ldots, r_{M_r}$) from a_c to a_d and calculates $m^r_1, \ldots, m^r_{M_r}$, which correspond to the proportion s_p selects $r_1, \ldots, r_{M_r}$, respectively. We denote by r_{max} the wired path r_i such that m^r_i is the maximum among those of all wired paths. The behavior of m^r_i is the same as that of m^a_i.

Behavior of activity The best wired path from a_c is the one with the highest throughput among all wired paths to a_d. If several wired paths have the maximum throughput, wired paths with a small number of hops are preferred. Thus, we define the activity α of wired path selection as follows:

$$\frac{d\alpha}{dt} = 0.1 \times \left(\left(\frac{l^r_{r_{max}}}{l^r_{max}} \right)^6 \times \left(\frac{h_{min}}{h_s} \right)^6 - \alpha \right), \qquad (4)$$

where l^r_{max} is the maximum throughput among all wired paths from a_c to a_d, $l^r_{r_{max}}$ is the throughput of r_{max}, h_{min} is the number of hops of the best wired path, $h_{r_{max}}$ is the number of hops of r_{max}, and h_s is the value that $h_s = \max\{h_{r_{max}}, h_{min}\}$. Thus, s_p is likely to select the wired path with high throughput and small number of hops.

4 Simulations

In this section, we verify that our protocol can appropriately select APs and wired paths that can avoid bottle-neck links by simulations. We compare our protocol with the greedy based protocol. First, we explain about the greedy based protocol. The greedy based protocol selects an AP based on Fukuda's protocol[3]. In the greedy based protocol, when STA s_p changes its AP from a_i to a_j, it stores the throughput of the route via a_i to use as the evaluation of a_i. The stored throughput is deleted after a certain period in order to update the information. The greedy based protocol selects an AP that has the highest evaluation, that is, it selects AP a_i such that the throughput of route via a_i is high (if it connects to a_i or it stored) or the throughput of wireless link is high (otherwise). After that, it selects a wired path that has the highest throughput from the AP it connects to. If several wired paths have the highest throughput, a wired path with minimum number of hops is selected.

4.1 Simulation settings

We set the simulation environment as a two-layered network which consists of one area F^u in the upper layer and 24 areas F^l_f $(0 \leq f \leq 23)$ in the lower layer. Each area is a 50m × 50m square field. We deploy these areas sparsely so that each STA cannot connect to APs in different areas. In the area F^u, there are 12 APs $a_0, \ldots, a_{11}$ and no STAs. In each area F^l_f, there are 4 APs $a_{f,0}, \ldots, a_{f,3}$ and 60 STAs $s_{f,0}, \ldots, s_{f,59}$. APs $a_{f,0}$, $a_{f,1}$, $a_{f,2}$, and $a_{f,3}$ are positioned at $(12.5, 12.5)$, $(37.5, 12.5)$, $(12.5, 37.5)$, and $(37.5, 37.5)$ in area F^l_f, respectively. Each AP has communication radius 40m and capacity 50Mbps. Each STA is randomly positioned in its area. We set the packet error rate $P_{p,i} = 0.8 \times (dist(s_p, a_i)/40)$, where $dist(s_p, a_i)$ is the distance between s_p and a_i. Each AP is connected by wired links (a_i, a_{i+4}), (a_{2j}, a_{2j+5}), (a_{2j+1}, a_{2j+4}) and (a_5, a_6) $(0 \leq i \leq 7$, $0 \leq j \leq 3)$. Each AP in the lower layer connects to one AP in the upper layer such that there are wired links $(a_{x,y}, a_{4\times(x \bmod 3)+y})$ $(0 \leq x \leq 23, 0 \leq y \leq 3)$. Each STA s_p in area $F^l_{f_1}$ selects its destination

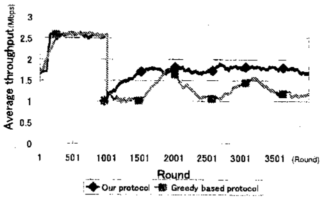

図 1: Simulation result

STA $t(s_p)$ in area $F^l_{f_2}$ such that $(f_1 \mod 3) \neq (f_2 \mod 3)$. Each source-destination STA pair is symmetric, that is, if $t(s_p) = s_q$ then $t(s_q) = s_p$. Notice that, each STA cannot connect to the AP that its destination STA connects to. Our simulation executes 4000 rounds. We set the capacities of all wired links initially 600Mbps. At round 1000, we degrade the capacities of wired links (a_{2j}, a_{2j+5}), (a_{2j+1}, a_{2j+4}) and (a_5, a_6) $(0 \leq j \leq 3)$ to 100Mbps. Each STA should select an appropriate AP to avoid bottle-neck links after round 1000.

For both our protocol and the greedy based protocol, each STA is activated exactly once every round. The interval of AP selection is varied from 100 to 150 rounds, and the interval of wired path selection is varied from 10 to 15 rounds. We set the period each STA stores the throughputs of routes in the greedy based protocol from 600 to 900 rounds so that the STA can know the throughput of routes via all APs in its area.

4.2 Simulation results

Figure 1 shows changes of the average throughput in one of the simulations. We executed simulations several times and all results show similar movement. In rounds 1 to 1000, the average throughput of our protocol is almost the same as that of the greedy based protocol.

After round 1000, since the capacities of several links are degraded, the average throughputs of both protocols are also degraded. However, our protocol gradually increases the throughput and keeps it. This shows that, even when the capacities of several links are degraded, our protocol can adaptively select APs and wired paths that attain higher throughput. This is because, when the environmental changes occur, the throughput of each STA is degraded and the activity of each STA is also degraded in our protocol. This causes that each STA randomly changes its AP and its wired path to adapt the current environment. Once each STA selects an AP and a wired path that attain high throughput, it continuously selects them with high probability. On the other hand, in the greedy based protocol, the average throughput temporarily becomes high around round 2000, however it is readily degraded. This is because, in the greedy based protocol, while each STA stores the throughputs of routes via all APs, it can select an AP with considering the throughputs of wired paths. However, the stored throughputs are discarded after a certain period and then each STA selects an AP with considering only the throughputs of wireless links. This causes that each STA selects an AP such that the STA must communicate with the destination STA via bottle-neck links and the throughput of the STA becomes low. This shows that our protocol has high adaptability to the large environmental changes.

5 Conclusion

In this paper, we proposed an attractor-selection based routing protocol in wireless LANs. In our protocol, when each STA connects to an AP with low throughput, it randomly changes its AP. After each STA connects to an AP with high throughput, it continues to connect the AP. By this way, our protocol can adaptively select an AP and a wired path with only local information. We showed by simulations that our protocol selects APs and routes adaptively to environmental changes.

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