

On Dynamics of Field Based Anycast Routing in Wireless Mesh Networks

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Abstract— We investigate the dynamics of field based anycast routing (FAR) in wireless mesh networks (WMNs), which is a hybrid routing scheme of geographic routing and back-pressure routing. Conventional FAR is equipped with a constant tuning parameter which controls degrees of influences of geographic routing and back-pressure routing. This generic feature limits the capability of FAR only for a certain network environment. In this paper, we consider dynamically evolving tuning parameters so as to develop a self-adjusting FAR (SAFAR) for changeable network environments. Beyond the conventional form of the tuning parameter, a constant function, we newly consider a step function and a Gaussian function for developing SAFAR. We provide mathematical analyses and simulations to assess SAFAR with two functions.

Keywords— Anycast, Back-Pressure Routing, Field Based Routing, Gaussian Function, Wireless Mesh Network

I. INTRODUCTION

The recent advance of wireless mesh communication technologies conveys the load-balancing problem of multiple mesh nodes. FAR (field based anycast routing) [1] has been proposed to solve both the load-balancing and routing overhead minimization for finding an efficient path. FAR is a kind of a hybrid protocol of geographic routing [2]-[4] and backpressure routing [5], which combines strengths of two routing schemes. In other words, FAR strives to find the shortest path with low overhead while achieving throughput-optimal in mitigation of traffic congestion. Here, a tuning parameter of FAR determines the reflecting ratio between geographic and traffic components. The conventional tuning parameter of FAR is a form of a constant function with respect to queue length. This feature limits the capability of FAR only for a specific network traffic environment. Therefore, we study appropriate forms for the parameter, which dynamically adjust the ratio of the queue sensitivity to the node distance.

The contributions of this paper are twofold:

First, we mathematically address several forms for the tuning parameter such as a constant function, a step function, and a Gaussian functions. The constant function maintains the fixed queue sensitivity independent on the queue length of a node. Differently, a step function and a Gaussian function dynamically change the queue sensitivity proportional to the queue length of a node. By controlling the coefficients of both

functions, we can achieve appropriate routing behaviors.

Second, we evaluate the selected forms for the tuning parameter via simulations under a practical IEEE 802.11 based WMN environment. We observe that the tuning parameter with a Gaussian function is stable and effective in normal and congested network scenarios.

The rest of this paper consists of as follows. We review related literatures in Section II. Next, we propose forms of self-adjusting field based anycast routing (SAFAR), which dynamically consider the traffic state of a network in Section III. Section IV provides simulation results to assess several functions for the tuning parameter. Finally, we conclude our paper in Section V.

II. RELATED WORK

The field based routing was initially introduced for unicast [6]. Thereafter, anycast routing protocol based on potential fields was proposed by V. Lenders et al. [7]. The former protocol uses the information of each node. On the other hand, the latter protocol (FDMR; finite difference method routing) takes the data of not only a node, but also one-hop neighbor nodes. Thus, the potential field of FDMR is more stable than that of [6].

FAR also utilizes a finite difference method [8] similarly to FDMR, which contributes to being locally stable with low overhead. However, FAR is only proper for no-dynamic environment since the tuning parameter of FAR is a constant function. To enhance FAR, we observe a step function and a Gaussian function.

A step function is a family of piecewise constant function with finitely many discontinuity points on the real number. The Bernoulli function [9], the Rademacher function [10], the Walsh function [10], and the Haar function are examples of the step function. These functions are applied in signal processing. Especially, the Heaviside step function with the Dirac delta function is often used in mathematics and physics [11].

The graph of the Gaussian function is a symmetrical bell-shaped curve. This has a single peak according to the central limit theorem [9]. Because of this feature, the Gaussian function is widely used in various fields. Most well-known examples are the normal distributions [12], Gaussian filter in signal processing [13], Gaussian blur and image warping in image processing [14], Gaussian beam in a microwave system,

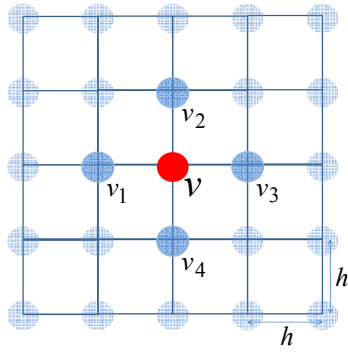


Figure 1. An example of the finite difference method.

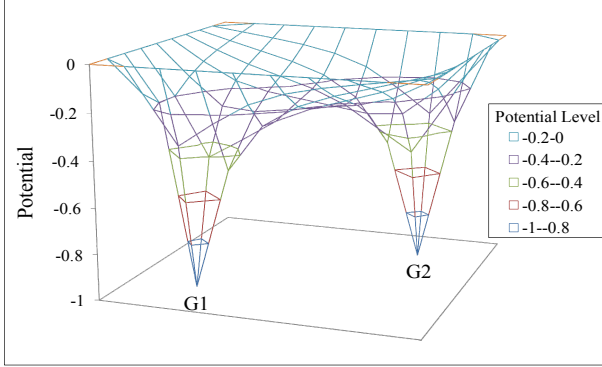


Figure 2. Stable potential field.

mathematical methods for solving heat equations and diffusion equations [15], and the Gauss-Markov mobility model is used for mobility patterns in mobile ad-hoc networks [16][17]. Moreover, the Gaussian function goes to zero at plus and minus infinity. Based on these characteristics of the function, we adopt a Gaussian function as a tuning parameter.

III. SELF-ADJUSTING FIELD BASED ANYCAST ROUTING

In this section, we provide a brief overview concept of FAR. Then, we analyze the tuning parameters – a constant function, a step function, and a Gaussian function – with a mathematical perspective.

A. Concept

We consider a directed graph $G=(V,E)$ with a set of nodes V and a set of directed links E to build a WMN. FAR is based on Poisson's Equation [18] in two-dimension:

$$\nabla_{xy}^2 \phi = -\frac{1}{\epsilon''} \sigma, \quad (1)$$

Here, ϕ is a potential (V), ϵ'' is a permittivity (C/V), and σ is a surface charge density (C/m²). To apply an FDM with a central difference, we obtain potential ϕ_v^{n+1} in $(n+1)$ time for each node $v \in V$.

$$\phi_v^{n+1} = \sum_{i=1}^4 \phi_{v_i}^n / 4 + \alpha(q_v^n) \cdot q_v^n, \quad (2)$$

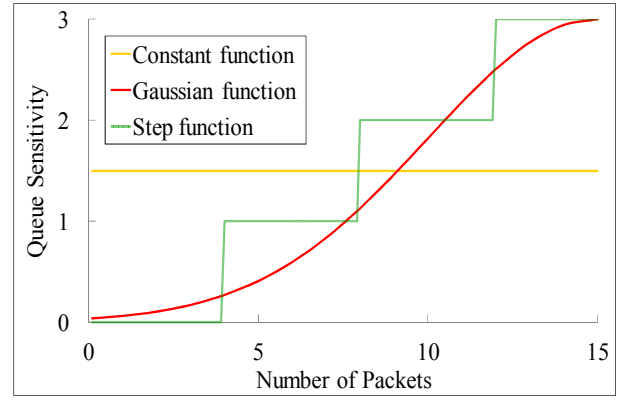


Figure 3. Graphs of the tuning parameters with a constant function, a step function, and a gaussian function.

TABLE 1. SELECTED THREE FUNCTIONS FOR α

Name of Function	Equation
Constant function	F_c
Step function	$\frac{F_s}{Ns-1} \cdot \left[\frac{Ns \cdot q_v^n}{Q_s} \right]$
Gaussian function	$F_g \cdot e^{-A(q_v^n - Q_g)^2}$

where v_1, v_2, v_3 , and v_4 are the elements of a set N_v which contains one-hop neighbour nodes, as shown in Figure 1. q_v^n is a queue length of the node v in (n) time and $\alpha(q_v^n)$ is a queue sensitivity depending on q_v^n . The equation is comprised of the average potential of N_v and the potential increase depending on q_v^n .

In addition, we set the boundary conditions. The potential of gateways are -1 and those of boundary nodes are 0. As the initial values, non-boundary nodes are set to 0. Each node iteratively performs Eq. (2) to establish a stable potential field as represented in Figure 2. For a packet transmission, a node v exchanges information of ϕ with elements of N_v in order to calculate ϕ_v^{n+1} and sends a packet to $\arg \min_{v_i \in N_v} \phi_{v_i}^n$. Based on this process, all packets arrive to one of mesh gateways which have the lowest potential.

B. Mathematical Analysis

As the effectiveness of the permittivity on an electrostatic potential field, a characteristic of $\alpha(q_v^n)$ greatly influences on FAR. In this paper, we compare a constant function, a step

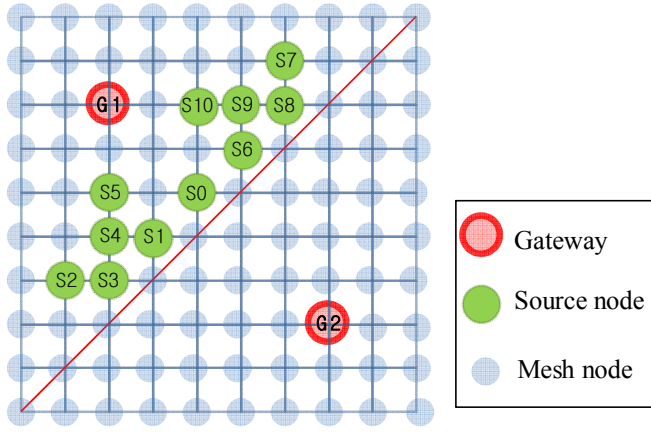


Figure 4. Simulation environment

function, and a Gaussian function for $\alpha(q_v^n)$. (Refer to Table 1) Mathematically, we analyze each function and conjecture characteristics of tuning parameters in a network.

1) **Constant function:**

- It maintains fixed queue sensitivity irrespective of q_v^n .
- Since it does not convey the self adjusting capability in a changeable network environment, it causes congestion in extreme cases such as $q_v^n \ll Q_c$ and $q_v^n \approx Q_c$,

2) **Step function:**

- It is proportional to q_v^n .
- It is a piecewise constant function having N_s pieces.
- There exist the jump discontinuity points at the end of the each piece of q_v^n .

3) **Gaussian function:**

- It continuously increases.
- It is convex when $0 < q_v^n < Q_g - 1/\sqrt{2A}$ and it is concave when $Q_g - 1/\sqrt{2A} < q_v^n < Q_g$.
- The proper constant A determines the shape of the graph. If $A \rightarrow \infty$, $\alpha(q_v^n)$ is close to zero when $q_v^n \ll Q_g$ and it is convex over the entire interval.

IV. SIMULATIONS

We construct a simulation environment based on the IEEE 802.11 PHY/MAC model. As shown in Figure 4, we deploy the 100 mesh nodes in a 10×10 lattice topology. Among the 100 nodes, two nodes are selected as gateways (G1 and G2) and the others are set to normal mesh nodes.

To make a network congested, we take the eleven source nodes (S0-S10) nearby the diagonal between G1 and G2. Each

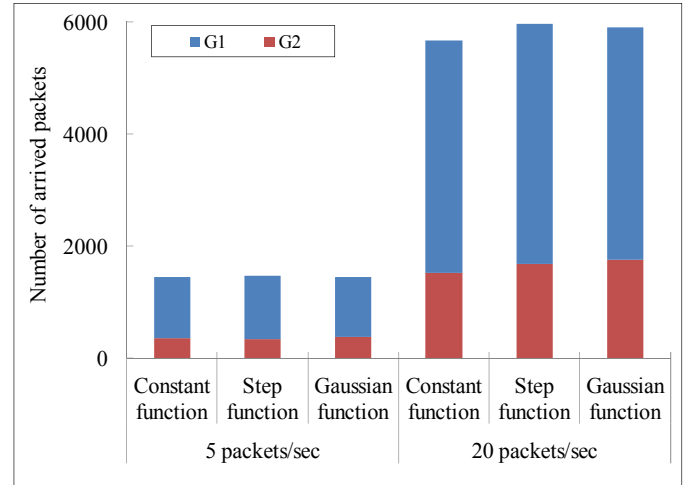


Figure 5. Ratio of arrived packets in two gateways for 5 packets/sec and 20 packets/sec, respectively.

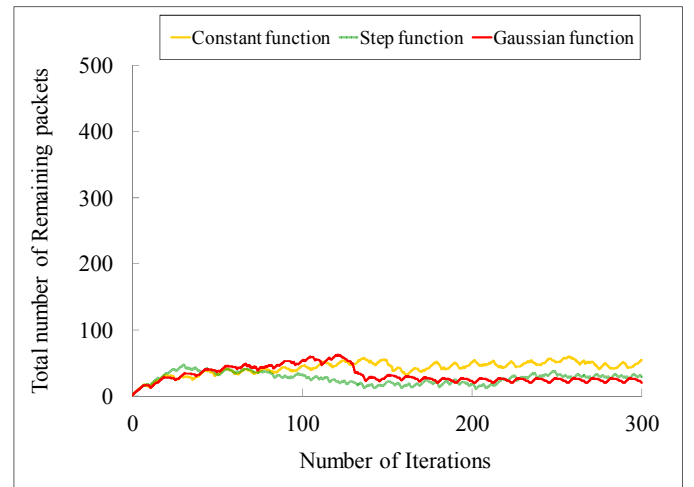


Figure 6. Total number of remaining packets in a network (sending 5 packets per second).

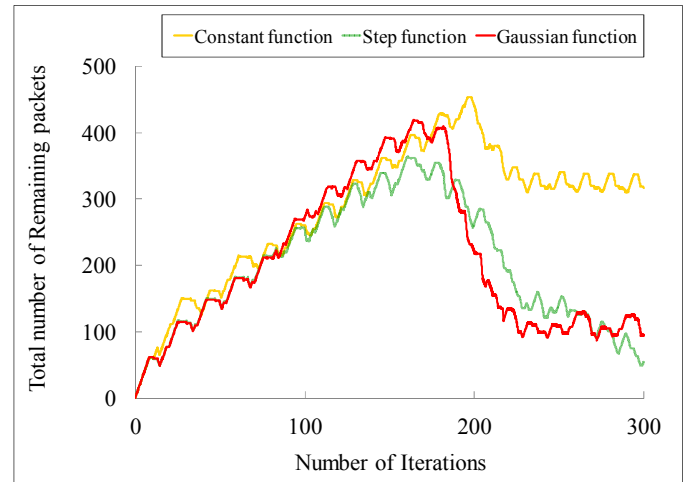


Figure 7. Total number of remaining packets in a network (sending 20 packets per second).

source node generates a packet in a constant bit rate. We observe the results of 300 seconds after setting up a stable

potential field. In this paper, we consider two sending rate cases, 5 and 20 packets per second, respectively. For the case of 5 packets per second, we set $F_c = 0.01$, $F_s = 0.04$ and $F_g = 0.04$ whereas for that of 20 packets per second, we assign $F_c = 0.0022$, $F_s = 0.005$, and $F_g = 0.006$, respectively. For dynamical performance, we assume $\alpha(Q_g) = 3\alpha(Q_g/2)$ for all cases.

With these proper coefficients, we obtain similar performance outcomes of backpressure routing as illustrated in Figure 5. The numbers of arrived packets in G2 are almost the same. The ratio of arrived packets at G1 and G2 is determined by the impact of hybrid routing of geographic routing and backpressure routing. Since the total number of arrived packets of the constant function is lower than that of the other functions, we predict that tuning parameters with a step function and a Gaussian function are appropriate for dynamic network environments.

Figure 6 and 7 show the total number of remaining packets in a network sending 5 and 20 packets per second, respectively. In Figure 6, there is only little gap between the constant function and the other functions contrary to Figure 7. In that figure, the trends of graphs are similar until 190 iterations. Thus, the network environments with three tuning parameters are analogous. From the peak point, the potential field fluctuates and the stacked packets are transferred along to gateways fast.

In case of the constant function which has the fixed queue sensitivity, the potential field inappropriately fluctuates compared with two other tuning parameters. At that point, the field forwards only few packets and traffic congestion is not solved. Therefore, the total number of arrived packets is less than that of the other two functions.

On the other hand, the tuning parameters with a step function and a Gaussian function are effective for a dynamically changed network. In a congestion state, the protocol of each function transfers the packets to the gateways in a short time. Thereafter, it sustains an equilibrium state of a network environment.

However, there exists a difficulty to handle a step function. The performance outcome is affected by the number of the pieces but we could only obtain proper values by trial and error. Thus, it is impossible to fix the number with the obvious standard before starting a simulation. Consequently, a Gaussian function is proper to the tuning parameter of SAFAR.

V. CONCLUSIONS

In this paper, we develop SAFAR (Self Adjusting Field-based Anycast Routing) for dynamic network environments to enhance FAR. In simulations, we observe that routing stability is affected by a tuning parameter in a congestion network environment. To obtain the optimal Gaussian function form, we control the coefficients of the function. The routing protocol with the Gaussian function achieves the autonomous load-balancing in the congestion environment. Moreover,

there exist less remaining packets in the network. Therefore, we address that SAFAR with a Gaussian function properly reacts to a dynamic traffic environment.

As future work, we provide the proof of the field stability and implement our scheme in three-dimension

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