무선 메쉬 네트워크에서 최소 간섭과 최적의 주파수 대역폭을 이용한 CDS 구성

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A Distributed Bandwidth-Interference aware CDS (BI CDS) Construction Scheme in Wireless Mesh Network

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요 약

무선 애드록 네트워크의 특수한 형태인 무선 메쉬 네트워크는 최근 새로운 연구과제의 초석으로 주목받고 있다. WMN의 제한적인 동작 환경으로 인하여 효과적인 연결 Dominating set 구성은 브로드캐스팅, 라우팅, 혹은 가상 백본을 구성을 위한 방법 중 하나로 중요한 관심대상이다. 본 논문에서 분산적인 방법을 토대로 네트워크에서 최소지연과 효율적인 대역폭 사용을 통하여 성능 향상을 시키기 위하여 Interference와 Bandwidth을 Dominating set 구성 파라미터로 사용한 연결 Dominating set 구성 알고리즘을 제안한다. 시뮬레이션을 통하여 제안된 알고리즘은 최대의 주파수 대역폭을 가진 링크와 연결된 최소의 연결 Dominating set이 구성됨으로써 네트워크 전체 성능이 향상됨을 보여준다.

ABSTRACT

As a special type of Wireless Ad Hoc Networks, Wireless Mesh Networks (WMNs) have become the corner stone of research issues. Due to the limited operational environment of WMNs, an efficienct connected dominating set (CDS) construction scheme is an important concern since it has been found extremely useful in broadcasting, routing and virtual backbone construction. In this paper, we propose a distributed Bandwidth-Interference aware CDS construction scheme to improve the network performance via two parameters such as node's number of neighbor and link bandwidth. Our CDS construction scheme selects the node that has more neighbors and enough bandwidth to support more end-devices in order to enhance overall network throughput and reliability. We confirm through simulations and show that our scheme constructs the CDS with the small subset of DS and the link that has better bandwidth.

키워드

Wireless Mesh network, Connected dominating set, Interference, Bandwidth

Ⅰ. Introduction

As a special type of Wireless Ad Hoc Networks, Wireless Mesh Networks (WMNs) have become the corner stone of research issues. By connecting intermediate nodes (i.e., routing nodes) wirelessly, WMNs can support large business

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enterprise by providing broadband networking infrastructure and residence in rural area by allowing Internet connection [1]. However, due to the limited operational environment of WMNs, many researchers still struggle for determining a solution for a specific problem (for example, virtual backbone construction, cross layer design, network topology control for saving energy in WMNs). Among them, a virtual backbone construction scheme is an important issue since it has been found extremely useful in broadcasting[2], routing[3][4][5][8], and data aggregation[6] in WMNs. The most typical approach of virtual backbone construction in wireless networks is the connected dominating set (CDS) construction [3][7][9][10][11]. A good CDS construction scheme should be distributed by using local information to determine node status in the network topology. As a result, the network can be scalable through localized preservation in a dynamic environment because the status of each node does not depend on the status of its neighbors.

WMNs are composed of three distinct types of connections - end devices to mesh routers, mesh routers to mesh routers, and mesh routers to gateways. By seamlessly interconnecting the smallest subset of intermediate nodes in WMN, all stations can communicate each other. However, such an approach overlooks the following three key issues and is likely to result in poor performance; distinct connection, adaptive transmission rate, and link bandwidth.

The most previous proposals in CDS construction schemes are considering on reducing the size of CDS and maximizing the energy efficiency [3][7][9][10][11]. While these schemes favor CDS with a small number of CDS and efficient energy, they do not take into account the bandwidth-effective CDS of a virtual backbone As a result, these scheme tend to produce lower overall performance in WMNs.

In this paper, we propose a distributed Bandwidth-Interference aware CDS (BI CDS) construction scheme to improve the network performance via two parameters: node's number of neighbor and link bandwidth. By selecting the node with the best link bandwidth to support more end-devices and the most number of nodes from the set of candidate mesh routers to reducing the possibility of the latency, the limited wireless resource can be better utilized. The simulation results show that the proposed scheme significantly improves the overall network performance.

표 1. 무선 프로토콜의 물리적 특성
Table. 1 Physical Characteristics of Wireless Standards

	802.11a	802.11b	802.11g
Mr	54Mbps	11Mbps	54Mbps
R	175 feet	300 feet	250 feet
Spectrum	5 GHz	2.4 GHz	2.4 GHz

M_r: Maximum rate R: Transmission range

Ⅱ. Network Model

Before proceeding in the presentation of the main paper ideas, we give some necessary definitions. A WMN is abstracted as an undirected graph $G = (V,E)$, where V is the set of all nodes in the network and E is the edge set with $(u, v) \in E$ *if and only if* u and v are within each other's transmission range. If G is connected, a set $V' \subset V$ is called a dominating set if for every vertex $v \in V - V'$, there exists a vertex $w \in V'$ such that $(v,w) \in E$. A dominating set is said to be connected if the nodes of the network is a connected subgraph of G spanned by the nodes of $V' \subseteq V$ such that every node in the network is at most one hop distance from a node in V.

In our proposed scheme, each mesh router, say x, maintains the *following two pieces of information:*

- *x's dominator*
- *x's state*

The dominator of x is one of the nodes, within the transmission range of x that falls in the dominating set. Notice that a node is its own dominator if it itself is in the dominating set. There are three possible states for a node, namely **init**, **marked**, and **dominator**. Initially, the state of all mesh routers is **init** except the gateway which has the state of **dominator**. The interference is assumed to be caused by adjacent neighbors' simultaneous communication within the transmission range. The signal strength is degraded by the inverse proportion to the distance under line-of-sight circumstance. In addition, the link bandwidth can be directly obtained by utilizing the signal strength. Mesh clients access to Internet through **DS** (i.e. mesh routers and a gateway).

To formalize the proposed CDS construction, an undirected graph G (Note that CDS already has been formed) needs to be simplified as following:

A mesh graph $G_M = (V_R, E_R)$, where V_R is the set of node vectors, and E_R is the set of link vectors. A node vector is defined as $V=<x, n>$, *where* x is a mesh router and n is the number of the mesh router x's neighbor. A link vector $<v_1, v_2>$, where v_1=<x, b> and v_2=<y, b>, represented a mesh link between x using bandwidth b and y.

Since the interference or collision happens while multiple mesh routers compete for same channel, the smaller size of **DS** is desirable in WMNs. We denote the number of elements in **DS** as |DS| (also referred to DS size) and the number of elements in E_{ds} as $|E_{ds}|$.

Since the signal strength is closely related to the distance between two nodes (sender and receiver). We formulate the available bandwidth of a mesh link *b(u,v)* is defined as below:

$$b(u,v) = M_r\,(1 - \frac{dist(u,v)}{R}) \qquad (1)$$

A mesh link between edge set with *(u, v)*, corresponding to a wireless link between *u and v* in set E_{ds} *if \ and \ only \ if* $dist(u, v) \le R$ where *dist(u,v)* is the distance between *u* and *v* and *R* is the range of the transmission. The possible maximum rate *Mr* and the transmission range *R* are shown in Table 1. Interference due to transmissions by adjacent nodes in a multi-hop WMNs affects network performance in a number of ways. In order to reduce interference in a WMNs, the node having the smallest number of neigher nodes should be selected as a dominator. As a result, the node, which has the maximum value of the production of the available bandwidth of links in the network and the least interference of the mesh routers, is selected as a dominator. An equation (2) is defined as a function of CDS selection among all connected nodes. The $N_n(v_i)$ is the number of v_i's neighbor.

$$\begin{aligned} CDS(v) = Max\,(& b < u, v_1 > \cdot N_n(v_1)), \\ & (b < u, v_2 > \cdot N_n(v_2)), \\ & \ldots, \\ & (b < u, v_n > \cdot N_n(v_n)) \end{aligned} \qquad (2)$$

Through an equation (1), the average link bandwidth $\overline{b_{ds}}(u,v)$ of Eds can be defined as below:

$$\overline{b_{ds}}(u,v) = \frac{\sum_{\forall (u,v) \in E_{ds}} b(u,v)}{|E_{ds}|} \qquad (3)$$

Ⅲ. Bandwidth-Interference Aware CDS (BI CDS) Construction

In this paper, we propose the BI-CDS construction scheme to improve the network performance via two parameter: node's number of neighbor and link bandwidth. The set covered problem has been specially adapted for the BI-CDS scheme to select a minimum number of sets. The sets we have picked contain all the elements that are contained in any of the sets in the input. In BI-CDS construction scheme, the node with the maximum value of the multiplication of the number of it's neighbors and the bandwidth is selected as the dominating node as shown in equation 2. In general, we prefer a dominator with lower latency and higher link bandwidth.

When mesh routers are distributed uniformly, a small CDS contains smaller number of hops and thus is likely to have less number of interfered neighbors. In addition, if a specific region has too many active communications, the link going through that region is likely to result in lower available link bandwidth. By choosing link with higher link bandwidth, a link that goes through a lighter traffic area can implicitly gain priority and load balancing can be achieved.

Suppose that the state of a gateway node immediately goes into **DOMINATOR**. It broadcasts information about its state to it's neighbor. A neighboring unmarked state becomes marked after receiving the message. Then, the marked state get the maximum value according to the equation (2) if it still has unmarked neighbors. It is obvious that nodes with more unmarked neighbors or higher link bandwidth result in shorter latency times compared with nodes with fewer unmarked neighbors and lower link bandwidth. When the calculation is done, the node with maximum value change it state to Dominator and broadcasts to its neighbor about its state. For an Dominator state, the message is sent every beacon period. This process will be continue until there is no more node which has the state of INIT by exchange control beacon message locally. The distributed low latency and bandwidth aware CDS construction algorithm is explained in Table 2.

표 2. 노드 *u*에서 CDS 선택 알고리즘
Table 2. CDS Selecting Algorithm at Node *u*

1. **for** each one-hop neighbor mesh routers $v \in E$ **do**
2. **for** each node $w \in E/v/$ **do**
3. if $b(u,v) * N_n(u_i) > b(u,w) * N_n(v_i)$ **then**
4. select *v* as a **CDS** from the neighbor list
5. **end if**
6. **end for**
7. **end for**

Ⅳ. Simulation

1. Simulation Environment

Mesh routers are randomly placed within this square region. Each mesh router in our simulation is assumed to be 802.11b which has transmission range of 100m. A gateway is randomly placed in the topology. We assumed that all traffics flow toward the gateway to access the Internet. The initial link bandwidth of each link is generated in a normal distribution.

표 3. 시뮬레이션 변수
Table 3. Simulation Parameters

Parameter	Value
Space	400 X 400 / 800 X 800
Transmission Radius	1
Number of Nodes	50-100

To get a good shape of result for the protocol performance under various topologies and smooth out the impact of some special topologies, 10 different network topologies are randomly generate in 400 X 400 and 800 X 800 with various node densities as shown in Table 3. The data collected by the NS2 network simulator are averaged for these 10 topologies.

2. Performance Evaluation

We present the performance of our distributed bandwidth-interference CDS construction method (referred as BI hence after) against the performance of Wu's (referred as WU hence after) algorithm which does not consider bandwidth for the network link quality. In addition, we also use two other metrics: Simple Neighbor Count (referred as SNC hence after) and Bandwidth-aware (referred as BA hence after) CDS methods for considering interference and link quality respectively.

To better understand the our suggest methods, an example is provided in this subsection to demonstrate how three methods (BI, SNC, and BA) work as shown in Figure 1.

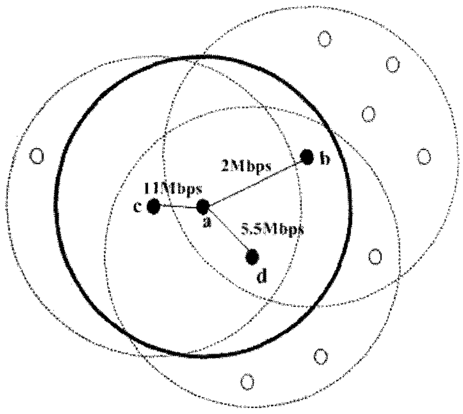

그림 1. 3가지 서로 다른 CDS 방법의 예
Figure 1. Example of Three different CDS methods

At the beginning, a gateway node a immediately goes to Dominator and rest of them are in init state according to our scheme. Then node b, c, d switch to marked state. After a period of time nodal, node b is selected as a dominator in SNC method since node b has the most number of neighbor nodes among other marked nodes(c and d). Node c is selected as a dominator instead of node b in BA method. In BI method, node d is selected as a dominator according to our CDS construction algorithm as shown in Table 1. The major advantage of SNC is that CDS size can be reduced significantly. The purpose of WMN research is to quickly provide Internet access to a large of number of mesh clients. Hence, network throughput should be the primary performance measurement. If the impact of interference can be reduced when the CDS is as small as possible, the over all throughput can naturally be increased. However, bandwidth is the precious resource to measure the throughput of a network. The transmission rate of a 802.11 wireless link can step down automatically when the signal strength is weaken. Since the signal strength is closely related to the distance between send and receiver nodes.

Therefore, by choosing node with the most neighbor nodes and with higher link bandwidth, a CDS can be likely to have less number of interference neighbors and goes through a lighter traffic in the network.

The results of CDS size in the different network size is observed in Figure 2 and 3.

As shown in Figure3 and 4, a SNC reduce the number of CDS size up to 50% compared to the Wu's protocol. Although the CDS size of SI is little higher than that of SNC, a SI also reduce the number of CDS size up to 37% compared to Wu's protocol.

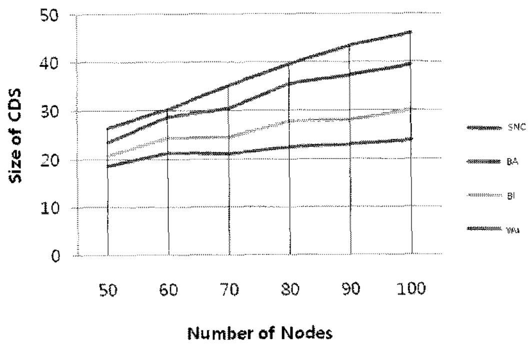

그림 2. 400 X 400 크기에서 평균 CDS 수
Figure 2. The size of CDS in 400 X 400

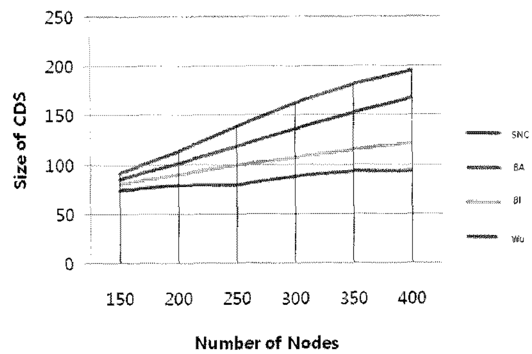

그림 3. 800 X 800 크기에서 평균 CDS 수
Figure 3. The size of CDS in 800 X 800

In Figure 4 and Figure 5, average link bandwidth among CDS has been traced by utilizing Equation (2) with respect to the number of mesh routers. As shown in Figure 4, Wu's protocol and SI have almost same level of average link bandwidth. Compared to the SNC, both Wu's protocol and SI improve the average link bandwidth up to almost 25%. This higher bandwidth indicates more mesh clients (i.e., end-users) can connect to the Internet simultaneously.

In some sense, it is noticed that better QoS can be provided in a network. Figure 5 shows that the average link bandwidth is degraded in SNC when the size of network is getting bigger. However, others are tolerant to the size of network. Therefore, our proposed SI is scalable to the network size.

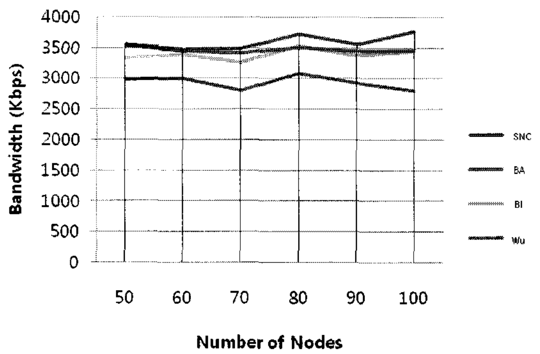

그림 4. 400 X 400 크기에서 사용된 링크 대역폭
Figure 4. The Link Bandwidth in 400X400

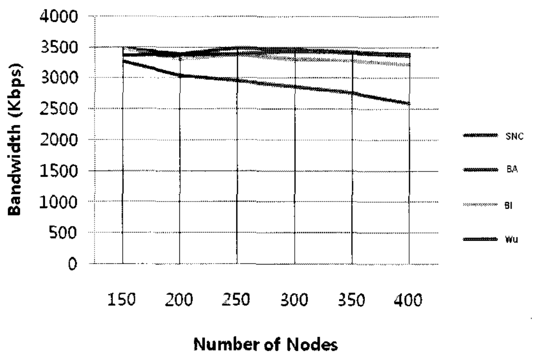

그림 5. 800 X 800 크기에서 사용된 링크 대역폭
Figure 5. The Link Bandwidth in 1000X1000

Ⅵ. CONCLUSION

In this paper, a distributed BI CDS construction scheme is proposed for WMNs to improve the network performance. BI CDS construction scheme accounts for both interference and link bandwidth constraints at each mesh router and link in the formulation of the selection of the node with high link bandwidth and most number of neighbor nodes. As a result, the proposed CDS scheme is able to increase overall network throughput in WMN.

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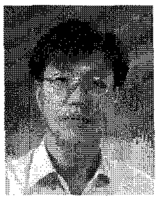

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