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Dynamic Clustering for Load-Balancing Routing In Wireless Mesh Network

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ABSTRACT

In this paper, we study the problem of load balancing routing in clustered-based wireless mesh network in order to enhance the overall network throughput. We first address the problems of cluster allocation in wireless mesh network to achieve load-balancing state. Due to the complexity of the problem, we proposed a simplified algorithm using gradient load-balancing model. This method searches for a localized optimal solution of cluster allocation instead of solving the optimal solution for overall network. To support for load-balancing algorithm and reduce complexity of topology control, we also introduce limited-broadcasting between two clusters. This mechanism maintain shortest path between two nodes in adjacent clusters while minimizing the topology broadcasting complexity. The simulation experiments demonstrate that our proposed model achieve performance improvement in terms of network throughput in comparison with other clustering methods.

Keywords: Routing Protocol, Load Balancing, Wireless Mesh Network, Algorithm

1. INTRODUCTION

There are three types of wireless mesh network (WMN) architecture [1,2]: Infrastructure/backbone, Client WMNs, and Hybrid WMNs. We consider the most promising architecture which is hybrid architecture. This network is divided into two distinct layers. Mesh client tier is composed of wireless mesh clients (WMC) which is limited power resources and may be mobile. Mesh router tier is composed of wireless mesh router (WMR) with backbone connection. WMRs have minimum mobility and do not have strict constraint on power. Due to these features of network architecture, cluster-based routing [3] is particularly suitable for WMN network. In this scheme, nodes in network are grouped into clusters based on some criteria such as position or topology. Network then is partitioned into many clusters. A node in cluster will be voted to be a cluster head. These cluster heads act as the local coordinator and they control cluster and nodes in that cluster. Applying this scheme to WMN, WMR should be cluster-head (CH) and clustering algorithm could be simplified to an algorithm that allows WMC to choose a WMR with minimal cost as CH. To take advantage of the backbone link between WMR, traffic generated at any WMC always goes through WMR (as CH) to a destination and reversely. For example in Fig. 1, when we need to route packets from node 8 to 3, directed route from nodes 8 to 3 through 7 may be better than the route over but it will not be used. Packet shall go through CH i and j to the

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destination 8.

One of the main concerns in wireless network with limited bandwidth is load balancing [4]. Especially in WMN, WMR is subjected to serve a number of different connections from WMCs concurrently. Traffic from all nodes in cluster will go to WMR. WMR becomes a bottleneck of cluster and downgrades the throughput of WMN. A clustering algorithm with considering of load-balancing between clusters in WMN that use clustering-based scheme is necessary to improve the performance of network. In this paper, we concentrate on problems of controlling load from WMC to WMR to balance traffic among WMRs in order to enhance overall network throughput. Depending on the current traffic pattern from WMC, we will allocate it to appropriate cluster to reduce the load from overload cluster head so improve the overall network throughput.

The rest of this paper is organized as follows. In the next section, we present related works and motivation in our research. In section 3, we will present the network model and assumption related to our research. In section 4, we will present an effective routing framework which supports for our load-balancing clustering algorithm. The simulation shows that the idea of this method can also apply for a general clustering routing method to reduce control overhead. In section 5, we will present load balancing model and algorithm to solve objective function of this problem. Simulation results are also presented in this section. In section 7 we conclude this paper.

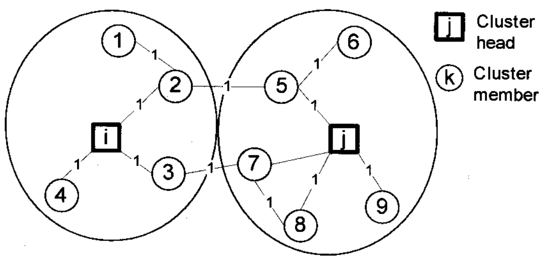

Fig. 1. Example of two adjacent clusters.

2. RELATED WORKS AND MOTIVATION

Cluster-based routing is a well-known method in network to solve scalability problem. For wireless network, many instance of this routing mechanism are presented in [3] and [5]. Reference [5] investigated in overhead of routing control. Beside, it also gives the overall view and main characteristics of this mechanism. Cluster-based routing can solve the scalability problem in ad-hoc network however the traffic load imposed by this method on the cluster head may cause degradation of network performance. Especially for ad hoc network, cluster head is a normal node with no enhanced capacity. This is one of reason why ad hoc network cannot be applicable for a high performance purpose. To improve network capacity while using clustering method, some of clustering algorithm proposed with consideration of load balancing between clusters. A weighted clustering algorithm (WCA) is proposed in [6,7]. In that method, they define a *load balancing factor* (LBF) to measure load of cluster as the inverse of variance of the cardinality of the clusters.

$$LBF = \frac{n_c}{\sum_i (x_i - \mu)^2} \quad \text{With} \quad \mu = \frac{N - n_c}{n_c}$$

Where n_c is number of cluster and x_i is cardinality of cluster i, and N is total number of node in the network. When this value is high, it means network is load-balanced in terms of nodes distribution. Definition of LBF in this way has advantage of simplicity however this factor cannot express all the features of network load which extremely depends on traffic pattern.

Other researches [8,9] use LBF as objective function to achieve a load-balancing state between clusters. Simulated annealing algorithm is used to approximate the optimization of the cluster allocation due to the NP-hard complexity of the problem. Again, this solution only considers the number of nodes as load factors. Besides, annealing algorithm can estimate problem but it requires centralized computation. This point affects seriously the scalability aspect of the algorithm. In the reference [10], author use the variant of the load on each cluster as the factor for load-balancing. This is approximation for the load-balancing between cluster. It may not reflect exactly state of network.

A clustering algorithm which is sensitive with traffic pattern can work much more effectively in the limited bandwidth network as WMN. In this paper, we approach clustering algorithm from point view of traffic demand on each WMC to build an optimal clustering algorithm.

Fig. 2 shows dependency of cluster throughput versus traffic generated by WMC in a cluster of one WMR and three WMC. Maximum bit rate is 1Mbps. In that experiment, when traffic from client is small rate, cluster throughput increases almost linearly with increment of traffic from WMC. But when WMC's traffic reaches a saturation point, named S, cluster throughput cannot be higher. That is optimal point for traffic at a cluster. As featured by the WMR, topology and many other conditions, the point S is not fixed for every cluster. Keeping total traffic from WMCs under S can offers a higher total network throughput. We consider WMR and WMCs which can connect to it as a cluster member. Each WMC can belong to a number of WMR. WMCs in WMC tier make overlapped areas between clusters. Key idea of our method is to share load between adjacent clusters and try to keep load

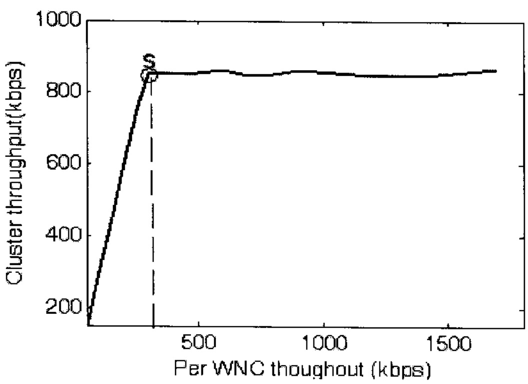

Fig. 2. WMCs traffic versus cluster throughput.

from WMCs imposed to WMRs under saturation point S. This is done by allocating WMC in the overlapped areas to appropriate WMRs.

We develop an optimization problem in order to find out optimal solution of the cluster allocation regarding the constraints of capacity of WMRs, current load on each clusters. However, regarding the complexity of the problems and the requirement of overall network status, which can lead to a centralized implementation of the method, we introduce an online algorithm based on the idea from [11-13] to obtain localized solution of the problem. Among that, the original idea is from [11]. [11] presented a load-balancing method that immediately assigns the load its neighbors which have lower load. Applying this idea to our problem, WMRs negotiate locally with its neighbors to distribute load by re-allocating WMC in overlapped areas.

3. NETWORK MODEL AND DEFINITIONS

Network is modeled as an undirected graph G=(V, E), where V is a set of |V| nodes and E is a set of |E| undirected links connecting node in V. Notations will be used is define in the Table 1.

Table 1. Notation

Symbol	Definition
R :	Set of WMR
C :	Set of WMC
id_i :	Unique identification if node i
$N(i)$:	Set of adjacent node of node i
l_{ij} :	Link between two nodes i, j
c_{ij} :	Cost of link l_{ij}
p_{ij} :	Shortest path between two nodes i, j. Path is assumed to be symmetric meaning $p_{ij}=p_{ji}$
$\|p_{ij}\|$:	Length of the path p_{ij}
$\|\|p_{ij}\|\|$:	Length of the path p_{ij} in hop count
P_i^c :	Set of path to WMR such that each $p_{ij}^c \in P_i^c$ is a legal path with $j \in R$ and $i \in C$
Φ_i :	Total traffic from WMC to WMC or versus
Φ_i^S :	Saturation traffic of cluster Z_i

A cluster named Z_i is composed of a WMR R_i and a set of WMC C_i that is currently set to send packet to RT over that WMR. Cluster concept here is like one defined in hierarchical routing in [3]. Two clusters are called adjacent when their WMR are connected. A WMC C_i may connect to RT over number of WMR but only two shortest $|p_{ij}^c|$, $p_{ij}^c \in P_i^c$, are chosen to produce overlapping area of only two clusters. Let O_{ij} is overlapping area of Z_i and Z_j : $o_{ij} = Z_i \cap Z_j$ then Z_i and Z_j are called overlapped clusters. A WMC $C_m \in o_{ij}$ is called overlapped WMC. A cluster is called "*active cluster*" of a WMC when that WMC is allocated to send traffic to that cluster.

We introduce a parameter named *k-short* defined as follows. Assume that $p_{im}^c, p_{in}^c \in P_i^c$, $|p_{im}^c| \le |p_{in}^c|$, are two shortest paths from C_i to R_m, R_n. They are valid path only when $\|p_{in}^c\|/\|p_{im}^c\| \le k-short$. This parameter is introduced to control the size of the overlapped area in the network.

4. CLUSTER FORMATION AND MAINTENANCE

Topology broadcasting in WMN includes two parts: topology broadcasting at CT and topology broadcasting at RT. At RT, with limited mobility of the WMRs, packet control overhead for maintenance topology of WMRs is low. Proactive routing protocol [2] for ad hoc network should be used. The candidates are Wireless Routing Protocol [14] or Destination-Sequenced Distance-Vector Routing [15]. At CT, routing procedures is more complicated. At first, we look at the main idea behind this topology broadcasting procedure.

Assume that we have two adjacent clusters as presented in Fig. 3. Broadcasting link state to adjacent cluster's members permits cluster member chose the best way to the destination node and not always has to use backbone links.

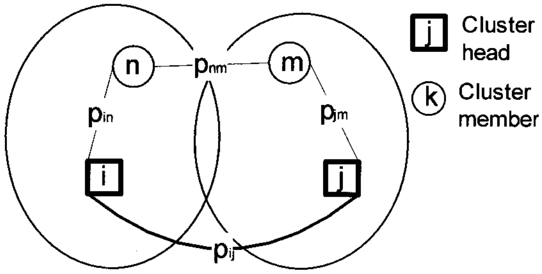

Fig. 3. Path between two WMC.

From point of view of node n, path p_{nm} is efficient only when

$$|p_{in}|+|p_{jm}|+|p_{ij}| \ge |p_{nm}| \tag{1}$$

Thus, we can have two constraints on broadcasting:

- Link state of a C_i will be broadcasted within its cluster
- Equation (1) will limit topology broadcasting of C_i to its adjacent clusters.

Implementation of the proposed routing protocol uses Link-states broadcasting technique and Dijkstra's shortest path algorithm. Above constraints are done by adding more information in the broadcasting packet, routing tables and several simple checking steps. Each WMR will hold two tables, cluster member table called *ClTb* and a table for topology control at RT called *RTTb*. *RTTb* is updated by using a proactive protocol as mentioned earlier. *ClTb* is update when a WMC requests to join the cluster. At CT, each WMC will also hold two tables, WMC table called *WCTb* and WMR table called *WRTb*. *WRTb* contains two valid shortest paths to WMRs. *WCTb* contains all valid path from that WMC other WMC within its cluster and adjacent cluster.

4.1 Cluster formation

CH-Claim packet is broadcasted from each WMR to its neighbor WMCs. CH-Claim packet of R_i contains *{id$_i$, D$_i$, Seq}*. D_i is the distance from WMC to the WMR. *Seq* is identification of the claim packet. When WMC receives a CH-Claim packet it should do as follows

- Update cost D_i according to the cost of the link it receives the packet. Record packet in to its memory and forward the updated packet.
- After timeout, get two smallest D_i and satisfies the *k-short* condition and then send cluster request packet to that WMRs.

After this, cluster formation phase is finished. We can see an example in the Fig. 4.

4.2 Limited Topology Broadcasting

Link state is broadcasted by all member of a cluster. Overlapped WMC will hold topology of both of overlapped clusters. Topology is hold in *WCTb*. Overlapped WMC C_g in the overlapped areas send packet P to all its neighbors on the adjacent cluster when receiving a link state update from any cluster member.

$$P = \{id_r, id_i, |p_{gi}|, |p_{ir}|\}$$

Packet P is sent following border-casting tree. At a WMC C_n in the adjacent cluster of C_m, C_n updates the packet P and follows border-cast only when (1) is satisfied. Otherwise, it drops the packet. At any node when (1) is satisfied, *WCTb* is updated. Cost is updated respecting to the current cost on the path to the changed node

$$|p_{mi}| = |p_{mg}| + |p_{gi}|$$

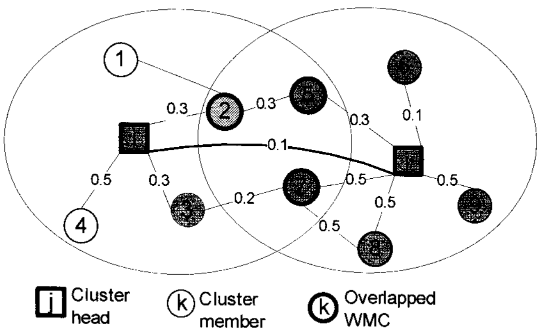

Fig. 4. Example of topology broadcasting and overlapped clusters.

Fig. 4 gives an example of topology covered by the proposed mechanism with 2-short. Nodes in gray are covered by link state broadcasting of node 8. This example present all principal of the routing protocol:

- Broadcasting from node 8 only covers node 3 because direct path p_{83} through 7 is better than path over backbone: 8-j-i-3
- 2, 5, 7 are overlapped WMC because they satisfies 2-short condition.
- Broadcasting from 8 covers all cluster members of Z_i.

To evaluate the effectiveness of limited broadcasting, we perform simulation of wireless network of 2 WMR on ns2. Cluster size is varied from 1 to 3 by change the number of WMC. When cluster size is 1, 2, and 3, number of node in each cluster is 4, 6, and 8, respectively. WMR is chosen as cluster head. In the simulation, WMCs communicate to form two adjacent clusters with an overlapped area. Link costs between nodes are changed randomly. We record the number of nodes that are affected by link cost changes when using limited broadcasting and conventional method. In conventional method, when a link cost change, link state is broadcasted to all cluster member and also all the adjacent clusters. Broadcasting to all adjacent clusters is needed to keep connectivity between WMC at WMC tier. Table 2 shows advantage of the limited broadcasting in comparison with the conventional broadcasting method. The average number of updated nodes when a topology changes from adjacent clusters is lower after when using the limited broadcasting method.

Table 2. Number of updated node when topology changed from adjacent cluster

Cluster sizes	1	2	3
Limited broad casting	8	12	16
Conventional method	5	6.8	9.1

5. LOAD-BALANCING ALGORITHM

In order to achieve load balancing state, we would like to keep load in every cluster under the saturation point *S*. This point and also traffic imposing by WMCs are different between clusters. When traffic load of a cluster is under saturation point, we consider it as underload. When traffic to a cluster is over saturation point, we consider it as an overload cluster. That overload part should be equally shared between clusters in the network. If total traffic at cluster Z_i is Φ_i, and traffic at saturation point is Φ_i^s , load-balancing problem for clustering in WMN will be:

$$Min \ \max\{|(\Phi_i - \Phi_i^s) - (\Phi_j - \Phi_j^s)|\} \ with \ \forall Z_i, Z_j \in V \quad (2)$$

The approach to solve this problem is to control Φ_i in each cluster by adjusting overlapped areas between clusters.

5.1 Model of load-balancing control problem

Traffic Φ_i loaded on R_i is total traffic generated by WMC in that cluster, it includes two types:

- Traffic rate generated by WMC which belongs to only a WMR. These nodes cannot connect to other WMR by constraint of *k-short*. Let it is Q_i(Fig.5).
- Traffic generated by overlapped area which is shared by overlapped cluster Z_i and Z_j, let it is q_{ij}.

Let $1+x_{ij}$ and $1-x_{ij}$ be portion of traffic that belongs to two the overlapped clusters. Total of that portion is 2 and $-1 \le x_{ij} \le 1$. At cluster Z_i, let $j \in M(i)$ are adjacent of R_i, total traffic of cluster Z_i:

$$\Phi_i = \frac{1}{2} \sum_{j \in M(i)} (1 \pm x_{ij}) q_{ij} + Q_i \quad (3)$$

In this formulation, "+" if $i > j$, "−" if $i < j$. Let A with size $||E'|| \times ||V'||$ be an incidence matrix of a network $G' = (E', V')$. V' is the set of clusters, $Z_i \in V'$; E' is the set of edge; each edge is overlapped area between two clusters, $O_i \in E'$. Let q_{ij}

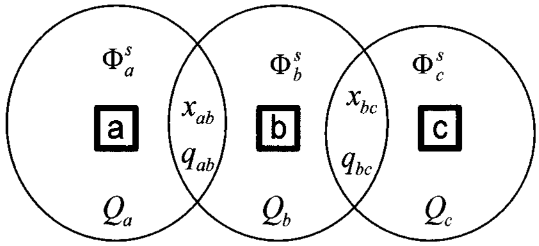

Fig. 5. Example of Traffic portion of WMRs.

is an element of vector q with size $||E'|| \times 1$. q_d is diagonal matrix with element of vector q. Q_i is element of vector Q ; $A_{abs}{}^T$ is the absolute of matrix the A^T. Then, total traffic generated by clusters can be defined by vector $\Phi_i(x)$.

$$\Phi_i(x) = \frac{1}{2}\left(A^T q_d x + A_{abs} q\right) + Q$$

At the cluster head, WMR can measure traffic generated by each WMC, then vector q and Q are known. Saturation point depends on circumstance of each cluster can also be measured by WMR then Φ_i^S is known parameter as well. Therefore, we can assume that Q, q and Φ_i^S are constants in a period of time. Let $\Psi i(x) = \Phi_i(x) - \Phi_i^S$ then our problems can be written as

$$\textit{Minimize} \ \max\{||\Psi_i(x) - \Psi_j(x)||\} \quad (4)$$
$$\textit{Subject to} \ -1 \le x \le 11$$

Problem (4) is a non-linear optimization problem with NP-hard complexity [16]. It cannot be solved using any well-known optimization method. Based on "*gradient method*" [11], we proposed an algorithm to find an optimal solution to problem (4).

5.2 Gradient algorithm

The gradient model is a localized load balancing method where every node interacts only with its immediate neighbors. A global balancing is achieved by propagation of the local load successively to neighbor nodes [11]. Speed of the propagation depends on the gradient of the load between nodes. For our system, this factor is defined as

$\gamma_{ij} = \lfloor |\Psi_i(x) - \Psi_j(x)| / (\Delta_{ij}^0 * 2 * \eta) \rfloor$ where η is an integer constant depending on system proposed to control the speed of coverage of algorithm and Δ_{ij}^0 will be mention later. Load exchanging between two clusters must consider the feature of the overlapped area, that is, dividable traffic. When there are more nodes in the overlapped area. Traffic of this area can be divided into smaller part. This feature is characterized by the parameters Δ_{ij}^0 and Δ_{ij}^x. Δ_{ij}^0 is smallest dividable capacity of overlapped area. In the network, that is the smallest traffic rate generated by nodes in overlapped area. Δ_{ij}^x is value of Δ_{ij}^0 but converted in to the presentation of x. When γ_{ij} is large, it means that difference of load between two clusters is high. The load moves faster toward the low load cluster to speed up the coverage of the algorithm. Applying the idea of algorithm to solve problems (4), we have to take into account the constraint of x which limits the freely sharing between two clusters.

Algorithm 1 shows algorithm for each R_i in the network. While performing the algorithm, R_i gradually get the load from the neighbors with higher load and share the load to neighbors with lower load. The algorithm will stop if the load cannot be exchanged between neighbors which happens in two cases. First, when difference of the load is smaller than the smallest dividable traffic. Second, when overlapped area becomes completely part of a cluster.

Algorithm 1 Gradient load-balancing clustering algorithm

For all $R_j \in N(i)$ *and* $\Phi_i > \Phi_j + \Delta_{ij}^0$
  If $i > j$ *then* $x_{ij} = x_{ij} - \gamma_{ij}.\Delta_{ij}^x$
  Else $x_{ij} = x_{ij} + \Delta_{ij}^x$
  Project x_{ij} *into [-1,1]*
Stop if $\Phi_i(t+1) = \Phi_i(t)$

5.3 Algorithm complexity

Features of the algorithm make its complexity become completely possible for real network implementation. Algorithm does not require global negotiation or parameters exchanging. Parameters exchange is require only within cluster and between adjacent clusters. Moreover, speed of coverage of the algorithm is controlled by η. Following lemmas will investigate the complexity of the algorithm

Lemma 1: Coverage of algorithm between two adjacent clusters can be achieved after at most η iteration steps

Proof: Let $\Delta_{ij}(t) = |(\Psi_i(x) - \Psi_j(x))|$ be difference between R_i and R_j at iteration t. Let a be a constant indicate the size of traffic will be moved between clusters. $\Delta_{ij}^0(t)$ is minimal dividable traffic in the overlapped area. Because nodes with smallest traffic are considered first then we have

$$\Delta_{ij}^0(t) \le \Delta^0_{ij}(t+1) \qquad (5)$$
$$\Delta_{ij}(t+1) = (\Delta_{ij}(t) - 2 * a.\Delta_{ij}^0(t))$$

Then after k steps and with (5), we will have

$$\Delta_{ij}(t+k) < \Delta_{ij}(t) - 2 * k * a * \Delta_{ij}^0(t) \qquad (6)$$

If after k steps if the right side of (6) reaches 0, the right side of (6) must also reach 0. We can calculate the value of k

$$\Delta_{ij}(t) - 2 * k * a * \Delta_{ij}^0(t) = 0$$

Then

$$k = \left\lfloor \Delta_{ij}(t) \Big/ 2 * a * \Delta_{ij}^0(t) \right\rfloor$$

If we chose the size of traffic to move between clusters as $\gamma_{ij} = \lfloor (\Psi_i(x) - \Psi_j(x)) / (\Delta_{ij}^0 * 2 * \eta) \rfloor$, maximum number of iteration to reach balance state between two clusters is η. By adjusting η we can control k which is the speed of load moving between clusters.

Lemma 1 shows that the speed of coverage of the algorithm perform between two WMC can be controlled by choosing the η. However, the coverage of the whole network depends on the number of adjacency of each WMR and also the network diameter. We do not study further more this problem on this paper.

5.4 Numerical example of the algorithm

We apply the algorithm to find the optimal solution of three overlapped clusters with given parameters in Table 3. We increase the Q_3 at clusters Z_3 while keeping others unchanged, and apply the algorithm. Fig. 6 shows the difference of traffic rates at WMRs versus the value of rate at WMR3. Applying the algorithms with $\Delta_{ij}^0=0.2$ and $\eta=1$, the differences of traffic rates are smaller. The difference is smaller since the traffic at overlapped areas is directed to the WMR which has smaller traffic rates.

Table 3. Values of Example

	q	Q	Φ_i
Z1	1.5	10	5
Z2	3	10	5
Z3	1	10	5

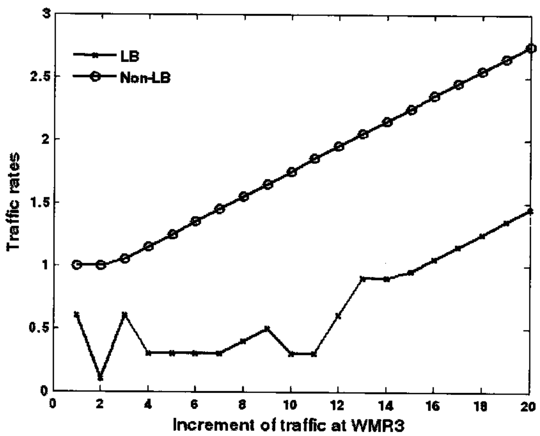

Fig. 6. Difference of traffic at clusters.

5.5 Experimental results

We perform simulation of WMN with three clusters to validate the performance of our algorithm in terms of network throughput. We use simulation platform ns2. The overall network throughput when applying load balancing clustering algorithm is compared with overall network throughput while using LBF. We form a WMN with 3 WMR and 12 WMCs. WMCs is distributed uniformly in the square of 500 meters x 500 meters. Network nodes are assumed to be immobile. In the MAC layer, we use IEEE802.11 protocol. Network bandwidth is 1Mbps. Packet size is 100 bytes. Traffic generation at WMC is CBR with the bit rate varies randomly node to node. The simulation scenarios assure total traffic generation from WMCs will cover a wide range to show efficiency of load-balancing method. Simulation is performed in two scenarios. In the first scenario, conventional method is used. Load-balancing criteria are LBF. Because WMC is located equally in each cluster, each cluster has 5 nodes. Then LBF will be infinite, the best LBF is achieved. In the second scenario, load-balancing clustering algorithm is used. Overlapped areas are formed between three clusters with clusters size of 1. WMRs applies the load balancing algorithm to allocate WMCs in orders to minimize difference of loads. Total traffic generated by WMCs and total throughput of network is calculated and shown in the Fig. 7.

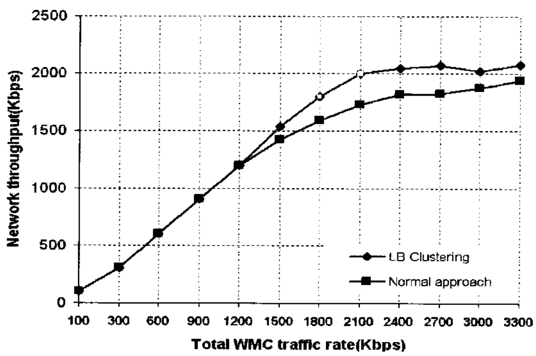

Fig. 7. Total network throughput versus total traffic by WMC.

The aggregate throughput when using the load balancing method is higher than the throughput in the network with the best LBF. At the low traffic rate of WMCs, two methods are almost the same because no clusters are overloaded. But when traffic is higher, some of clusters become overload. In the scenario of conventional method; clusters cannot share the load, the network throughput could not reach higher. This simulation shows the drawback of the load-balancing method which is insensitive with network traffic. Event with the best LBF, maximal network throughput cannot be achieved.

6. CONCLUSION

In this paper, we proposed a cluster-based routing framework basing on the well-known cluster-based routing frameworks. Basing on overlapped clusters, we proposed a algorithm to control load-balancing of WMR by distributing traffic generated from overlapped appropriately to WMR. The simulation result shows the advantage of our method in terms of enhancement of aggregate network throughput.

Parameter *k-short* is also an important parameter to determine how much clusters are overlapped. When k-short is set to be very small, clusters become separate. In that case, our algorithm can not be applied but cluster-based routing with limited broadcasting is still available. Then, depending on network configuration, we should choose a suitable *k-short*.

For the future work, we will deal with the load balancing problems at two tiers simultaneously. Especial, the load balancing model should be extended for multi-radio multi-channel network to enhance the network capacity.

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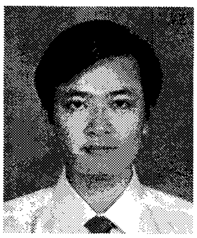

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