Congestion-aware Multi-Gateway Routing for Wireless Mesh Video Surveillance Networks

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***Abstract*—In video surveillance and monitoring systems based on wireless mesh networks, large volumes of multimedia data with different priorities and time demands are generated by video cameras and wireless sensors. Hence, one of the key issues is how to alleviate network congestion for highly reliable transfer of multimedia data towards gateways. This paper proposes a solution for utilizing multiple gateways to divert data streams and alleviate traffic congestion near a specific gateway. With a new routing protocol, named "Multi-Gateway Routing with Congestion Avoidance (MGR-CA)", network congestion can be predicted in a distributed manner and amounts of data traffic transmitted to the congested path are redirected to an alternative gateway based on the severity of congestion. Preliminary testbed experiments are made to show the performance of our scheme.**

Keywords- Wireless Mesh Networks; Multi-Gateway Routing; Video Surveillance

I. INTRODUCTION

Unattended surveillance and monitoring applications have been an important aspect of many electrical systems that require high-level security for defending against various physical attacks. Recently, there have been much research and progress on configuring these surveillance systems via wireless communication modules [1]. Multiple numbers of multimedia cameras can relay their data via the wireless medium, collaborating with each other to allow multi-hop transmission to the data collecting servers and users.

These wireless infrastructures, such as the IEEE 802.11s based Wireless Mesh Networks (WMNs) [2], can provide high-speed solutions while guaranteeing cost reduction, more flexibility, and better scalability compared to existing wired infrastructures. Especially, a default routing framework of the 802.11s, the "Hybrid Wireless Mesh Protocol (HWMP)", can provide various multi-hop routing strategies to provide efficient routing in wireless environments. Also, the 802.11s standard adopts the Enhanced Distributed Channel Access (EDCA) from the IEEE 802.11e [3] for QoS provisioning by utilizing access categories mapped into multiple data queues.

However, WMN may also bring various issues and problems when it is directly applied to the wireless surveillance systems. Video surveillance networks have properties that most of its generated data are from the interior network and propagated to exterior servers. In this process, overwhelming amount of multimedia data generated in a single network are transmitted and concentrated to gateways. Consequently, severe traffic congestion occurs, causing transmission of data packets to be deterred or even fail and hence failing to meet the reliability and QoS requirements. Especially, this problem becomes worse when emergency streaming events are sensed and generated in the network. This causes even more congestion and decline in the reliability of the network, even though high reliability is actually required in these emergency cases to successfully deliver these messages.

Up to now, some methods such as load balancing via utilizing multiple routing paths have been proposed to solve the congestion problem. Especially, multi-gateway routing is capable of distributing the traffic load to other areas of network to relieve congestion at certain points of network. Works such as [4] consider the load balancing problem to dynamically alleviate congestion by estimating the current congestion level at each gateway and deciding whether to accept or redirect current flows. When redirection is decided, the gateway will notify the node inducing the congestion to redirect all of its data to another gateway. The problem in these approaches is that they are centralized and can be inaccurate because the point of congestion is not always at the gateway.

In this paper, we propose a novel congestion aware routing method, named as *Multi-Gateway Routing with Congestion Avoidance (MGR-CA)* that implements multi-gateway routing in IEEE 802.11s based wireless mesh systems. Multiple gateways located in different areas of the network are utilized to divert data streams and alleviate traffic congestion near a specific gateway. Using distributed methods, the current congestion status is predicted by each node in the network to pinpoint the exact area of congestion. Upon congestion detection, amounts of data traffic transmitted to the congested path are redirected to an alternative gateway depending on the severity of congestion. The preliminary performance evaluation via testbed experiments shows that our proposed scheme provide better throughput and delivery ratio under congested scenarios to guarantee higher reliability in wireless networks.

II. PROPOSED SCHEME

The MGR-CA operates with multiple gateways located in the network. For creating multiple paths to different gateways, the MGR-CA uses the RANN message already defined in the HWMP. The RANN message is flooded to each node in the network periodically by each gateway. Through the RANN message, each node in the network can maintain a multi-hop path to the primary gateway and also an alternative gateway. To support better QoS, each mesh node maintains 4 prioritized queues based on the IEEE 802.11e EDCA MAC.

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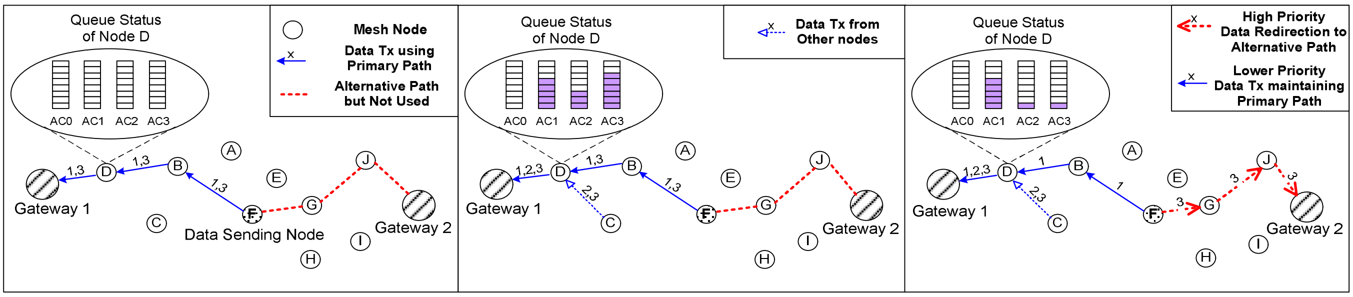


(a) No Congestion **(b) Congestion at Node D** **(c) Redirection of data to Gateway 2**

Fig. 1 An Example Scenario of the MGR-CA

A. Congestion Prediction

Our proposed scheme uses a distributed method where all the nodes in the network can predict its current congestion level. Therefore, our scheme can accurately pin-point the exact node suffering from traffic congestion and take proper actions to avoid and relieve its congestion. Each node can calculate its congestion level by checking the current queue level of each queue. We define the Path Congestion Level (PCL) to evaluate both the level of each queue and its priority:

$$PCL = \sum_{i=0}^{n-1} \left(\frac{Q_i}{Q_{max}} \times \omega_i \right) \tag{1}$$

where Q_i = queue level of a queue, $Q_{\max}$ = maximum queue level of a queue, ω_i = weight of priority, and n = number of queues. The equation (1) specifies that the current amount of packets queued in each queue (Q_i) is calculated according to the queue's priority weight (ω_i). Packets queued in a higher priority queue yields more weight values and causes the PCL value to grow more than packets in lower priority queues. The maximum queue length will depend on the hardware and the device driver of the WLAN card. For example, Madwifi driver developed for the Atheros AR5414 chipset [5] defines a maximum of 50 packets for each queue. The decision of the exact value of each weight can be specified by the system designer. In the experiment, we will present a reference value that we have derived and used from the EDCA parameters.

When the PCL value is acquired, it is then mapped into one of the five congestion degree (CD) values shown in Table 1. The range of the PCL values that are mapped to the CD can also be user-defined ranges. The sample PCL ranges corresponding to the CD are selected empirically, as shown in TABLE 1. Once the CD value is acquired, it is inserted in the RANN message and rebroadcasted. Every time a mesh node receives the forwarded RANN message, it will compare the CD value included in the RANN message with its own congestion degree. If its congestion degree is higher than the CD value inside the RANN, it will replace the CD value of the packet with its own value and forward the RANN message. It will also consider the higher value of the two CDs as the congestion level of the current path. As a result, each node will record the highest CD value among all intermediate nodes that is located between itself and the gateway that transmitted the RANN message.

TABLE 1 Bit settings for the PCL mapped with CD

Congestion Degree (CD) Value	Equivalent PCL Range
No Congestion (0)	$PCL_{min} \le PCL \le PCL_{int0}$
Weakly Congested (1)	$PCL_{int0} < PCL \le PCL_{int1}$
Med. Congestion (2)	$PCL_{int1} < PCL \le PCL_{int2}$
Highly Congested (3)	$PCL_{int2} < PCL \le PCL_{int3}$
Fully Congested (4)	$PCL_{int3} < PCL$

TABLE 2 Data Redirection depending on the RL

RL Value	Queue Redirection (Pri :: Alt)
RL < 0.5	(AC0, AC1, AC2, AC3 :: NULL)
0.5 < RL ≤ 1	(AC0, AC1, AC2 :: AC3)
1 < RL ≤ 2	(AC0, AC1 :: AC2, AC3)
2 < RL ≤ 3	(AC0 :: AC1, AC2, AC3)
3 < RL ≤ 4	(NULL :: AC0, AC1, AC2, AC3)

B. Congestion Avoidance

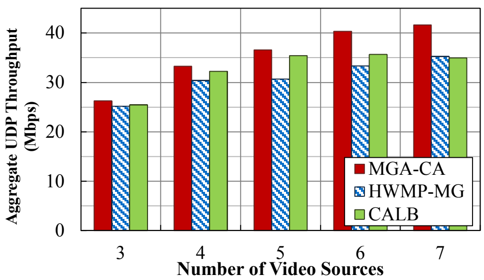
If a node receives or calculates a CD value bigger than 0, the node will realize that there is at least some congestion in its route and firstly compare the congestion level of the alternative route with that of the primary route. The node will initiate redirection policies if the congestion of the alternative route is less. Equation (2) is used to calculate the level of redirection and decide which queues will be redirected to the alternative route:

$$RL = CD \times \left(\frac{Cost_{primary}}{Cost_{alternative}} \right) \tag{2}$$

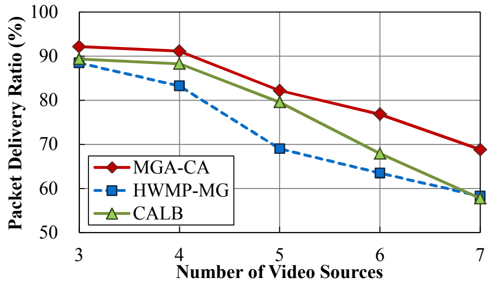
In equation (2), Redirection Level (RL) uses the airtime cost of both primary multi-hop routing path and the alternative routing path, where the airtime cost of each route is provided from the existing HWMP protocol. $Cost_{primary}$ is the airtime link cost of the current primary route and the $Cost_{alternative}$ represents the airtime link cost of the best alternative route to another gateway. CD is a value from {0, 1, 2, 3, 4}, as shown in Table 1. The queue redirection depending on the RL value can be seen in Table 2, where we can observe that the redirection of the queues to the alternative route occurs from the higher priority queues first. If lower priority queues are redirected first, it would be less efficient because data with higher priority are more time-critical and should be sent via a better route. This redirection of data is only initiated for data packets that are generated and transmitted for the first time to avoid looping problems.

C. Example scenario depicting our scheme

We can observe from Fig. 1 (a), that node F is transmitting two types of application with priorities 1 and 3 to its primary gateway. At the current moment in the example, the alternative route is not utilized as the nodes do not sense any congestion in its prioritized queues. However, additional data transmission



(a) Overall Throughput



(b) Packet Delivery Ratio

Fig. 2 Experimental Results using Mesh Testbed

from node C causes the queue level of Node D to increase, and decide that it is congested, as shown in Fig. 1 (b). Therefore, when node D receives a RANN packet from Gateway 1, it will include its CD value in the packet and rebroadcast. Eventually, the RANN will be forwarded to node F and it will realize that there is congestion at its primary route. Consequently, node F redirects its higher priority traffic of 3 to the alternative route, while the lower priority traffic is still transmitted via the primary route. From this redirection, the queue congestion in node D naturally becomes less as the load of the traffic is balanced throughout the network, as shown in Fig. 1 (c).

III. PERFORMANCE EVALUATION

To performance of the MGR-CA is evaluated via multiple-channel multiple-interface based testbed implementation. 11 mesh nodes including two mesh gateways are installed in an indoor environment. Each mesh node is operated via 2.6.33 Linux-based PCs, with two PCI LAN cards per each node. Each LAN card is equipped with a Atheros AR5414 Chipset that supports 802.11a operating in 5 GHz frequency range. Therefore up to 54 Mbps transmission rate can be supported for each interface. 7 orthogonal channels were evenly distributed between the nodes using breadth first search allocation. UDP traffic of 512Kbps, 4Mbps, and 4Mbps for AC0, AC2, and AC3 priority applications were generated respectively. One set of these traffic will be considered as a set of video source and transmitted by a random node in the network. All packets are transmitted to a target node outside the mesh network which is connected to the gateway via wired interfaces.

The performance of MGR-CA is compared with the traditional HWMP scheme that can utilize multiple gateways (HWMP-MG) and the Congestion Aware Load Balancing scheme in [4], which we abbreviate in this paper to CALB for convenience. Table 3 shows the reference values that we have configured for our evaluations of MGR-CA. It shows the weight of each queue, which we have obtained from EDCA parameters. Using these weight values, we can numerate the suitable congestion level of each node and then map them with the CD values shown in Table 1. For our evaluation, we have set the $\{PCL_{min}, PCL_{int0}, PCL_{int1}, PCL_{int2}, PCL_{int3}\}$ of Table 1 as {0, 8, 16, 24, 32}. These values can dynamically change depending on the environment of the network.

TABLE 3 Reference weight of each queue

Queue	AC	CW_{min}	AIFSN	Weight (ω_i)
AC0	BK	15	7	100/(15+7) = 5
AC1	BE	15	3	100/(15+3) = 6
AC2	VI	7	2	100/(7+2) = 11
AC3	VO	3	2	100/(3+2) = 20

Fig. 2 shows the experimental results in terms of aggregate throughput and delivery ratio. Fig. 2 (a) shows the throughput of the three schemes. We can observe that the MGR-CA performs better than its counterparts as the congestion of the network increases. Especially, when 6 video sources are generated, the MGR-CA outperforms the HWMP-MG by more than 20%. The saturation point of CALB is the lowest amongst all the protocols, located at 5 video sources. We have observed that this problem is due to the inefficient policy of CALB that it cannot pin-point the area of congestion and does not adapt well even if there are heavy congestion in the network. The MGR-CA is more resilient to congestion because it can better control the level of redirection by evaluating the priorities of each queue. Fig. 2 (b) also shows that more packets are arrived at the destination with more success in the MGR-CA, guaranteeing higher reliability.

IV. CONCLUSION

Wireless Mesh Networks can be the key technology in the realization of efficient unattended video surveillance systems. To cope with the large amounts of multimedia data that can cause congestion in mesh networks, we have proposed a congestion-aware distributed multi gateway routing method. More research and discussion will be needed for better design of our MGR-CA. For example, mathematical modeling of our proposed schemes will be a major part of our focus. In our testbed evaluation, sample reference values for the weights of each queue were used for calculating the congestion status of each node. However, these values were derived intuitively and may not be the optimal values in different types of environments. Also, construction of the realistic outdoor surveillance network based on our protocol is under progress, and more comprehensive evaluation will also be our future work.

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