2010 Symposia and Workshops on Ubiquitous, Autonomic and Trusted Computing

An Adaptive Cross-layer Mechanism of Multi-Channel Multi-Interface Wireless Networks for Real-Time Video Streaming

Jian Liu, Fangmin Li, Fei Dou, Xu He, Zhigang Luo, Hong Xiong
Hubei Key Laboratory of Broadband Wireless Communication and Sensor Network& School of Information Engineering
Wuhan University of Technology
Wuhan, China
Email: super.liujian@gmail.com, lifangmin@whut.edu.cn, doufei123@gmail.com, johnhexu@gmail.com, zealluo@gmail.com, xhadam3166@gmail.com

***Abstract*—Real-time video streaming over wireless links imposes strong demands on video codecs and quality of networks. Many measures are made to design proper routing protocols and channel assignments (CAs) for multi-channel multi-interface (MCMI) wireless networks, since it can provide higher performance than single channel. However, there still has not been a well-studied proposal to guarantee real-time video quality in this situation. Hence, it motivates us to explore the potential synergies of exchanging information between different layers to support real-time video streaming over MCMI wireless networks. In this article we jointly consider three layers of the protocol stack: the application, data link and physical layers, and propose an adaptive cross-layer mechanism for real-time video streaming (ACMRV) used in this scenario, which includes both an efficient CA and an adaptive FEC mechanism. We analyze the performance of the proposed architecture and extensively evaluate it via NS-2. The results show that the real-time video quality can be greatly improved by our proposal.**

Keywords- Cross-layer; ACMRV; MCMI wireless networks; Channel Assignment; Video Streaming

I. Introduction

To support the increasing popularity multimedia applications of wireless mobile devices, especially for some emergency scenarios, transferring real-time video streams over wireless networks has become a research focus recently. IEEE 802.11 [1] is a widely used wireless communication technology. Although the standard was developed for building single-hop local area networks, it has been used in multi-hop networks as well. IEEE 802.11 offers multiple non-overlapping channels. For example, IEEE 802.11b offers 3 non-overlapping channels, while IEEE 802.11a offers 12 non-overlapping channels. Typical multi-hop wireless network is based on a single common channel used by all nodes to ensure network connectivity, so that the network resources cannot be made full use of. Therefore, it is now commonly accepted that the presence of multi-interface enabled devices is going to be very likely in the near future. The rapid growth of IEEE 802.11 technology has eased the sharp decrease of the corresponding products' prices and therefore, their presence is more and more common day by day.

For real-time video traffic over MCMI wireless networks, since video packets are stale useless even if they can reach destination successfully, more consideration should be focused on the effects such as delay, jitter, and loss packet ratio, etc, What's more, wireless links are not very stable, channel conditions can change rapidly due to changing distance between the enabled devices in mobile environment. In MCMI situation, we need select which channel's state is better and more suitable for real-time video traffic, and unavoidable packet errors usually need to be recovered by using FEC (Forward Error Correction) technique[2].

In this article we proposed the ACMRV in MCMI wireless networks by cross-layer design. The information of network traffic load and wireless channel state can be obtained from medium access control (MAC) layer based on packet queue length and available bandwidth. In our proposal, redundant FEC packets are dynamically added and channel-using is switchable according to comprehensive information from MAC layer. From a number of experiments, we can draw the conclusion that the real-time video streaming quality over MCMI wireless networks can be greatly improved by applying our proposed method.

The remainder of this paper is organized as follows: Section 2 reviews other related channel assignment and researched works on FEC. Section 3 presents our proposed ACMRV, from a cross-layer model to an intelligent CA and adaptive FEC mechanism. Section 4 describes assumptions of simulation, our simulation environment and the simulation results. Finally, the last section draws conclusions and suggests future works.

II. Related Works

CA is a key technique to relieve signal interference and to increase network capacity in multi-channel wireless networks. However, existing algorithms either can not make efficient use of available channel resources for real-time video streaming, or

978-0-7695-4272-0/10 $26.00 © 2010 IEEE
DOI 10.1109/UIC-ATC.2010.9

have channel assignment coupled with routing and thus lack the practicality in the real world. FEC mechanism is a method commonly used to deal with losses in video streaming. Moreover, the conventional FEC mechanism still has the problem of burst packet losses in wireless networks.

A. Channel assignment for MCMI wireless networks

A number of channel assignment schemes have been proposed in recent years [3-7]. A new channel selection strategy is proposed in [3] that destination node selects the channel with the lowest total received signal strength. In [4], the authors investigate different forwarding channel selection schemes for MCMI communication with Destination Sequenced Distance Vector (DSDV) protocol: same channel, random channel and round robin channel, and thus conclude that the round robin one provides the best performance. Furthermore, an efficient joint channel assignment and routing protocol (J-CAR) for MCMI mobile ad hoc networks (MANETs) is proposed in [5]. It has couples of major features: a pre-determined common control channel is used by every node for routing and channel negotiation, while the spare capacity on the control channel can be used for data transmission. In a subsequence publication [6], a centralized heuristic algorithm for the channel assignment due to the NP-hardness of the problem has been developed to serve as a practical solution. However, we have selected P. Kyasanur's and N. H. Vaidya's channel assignment scheme in [7] for our extending of ACMRV, as this approach is more flexible and versatile compared with others.

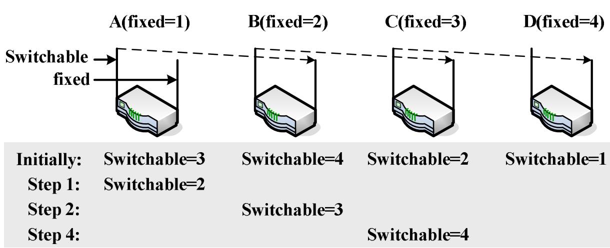

Figure 1. Example of CA with 4 channels, 2 interfaces

Each channel is associated with a packet queue, which is associated with N channels and 2 interfaces, one fixed interface and one switchable interface. The fixed channel is used to receive packets while the switchable ones used to send packets. Figure 1 illustrates the protocol operation. Assume that node A has packets to send to node D via node B and C. Nodes A, B, C and D have their fixed interfaces on channels 1, 2, 3, and 4, and switchable interfaces on channels 3, 4, 2 and 1 respectively. In the first step, node A switches its switchable interface from channel 3 to channel 2, before transmitting the packet, because channel 2 is the fixed channel of node B. Node B can receive the packet since its fixed interface is always listening to channel 2. In the second step, node B switches its switchable interface to channel 3 and forwards the packet, which is received by node C using its fixed interface. In the next step, node C switches its switchable interface to channel 4 and forwards the packet, which is received by node D using its fixed interface.

B. Forward error correction

Some of the earlier works [8-11] have addressed the issue of FEC. [8] proposes an Enhanced Adaptive FEC (EAFEC) algorithm implemented in the Access Point (AP) to improve video delivery over wireless networks. In [9], a novel adaptive FEC and interleaving architecture is proposed to offer better wireless bandwidth utilization through video data interleaving and less packet loss rate when compared with the Enhanced Adaptive FEC (EAFEC). The algorithm is based on two factors: one is the queue length in the access point, indicating network traffic load; the other is packet retransmission times, indicating wireless channel state. In [10], an FEC with Path Interleaving (FEC-PI), who sends interleaved data over multiple paths to overcome the FEC recovery performance problem due to the burst packet losses, is proposed to improve the quality of video streaming in a multi-path environment. Furthermore, an adaptive Sub-Packet FEC (SPFEC) mechanism is proposed in [11] to improve the quality of video streaming data over wireless networks, simultaneously enhancing the recovery performance and reducing the end-to-end delay jitter.

III. ACMRV OF MCMI WIRELESS NETWORKS

Due to the increasing trend of using wireless communication MCMI devices, several researchers including this type of nodes have been tried to extend their analysis and simulation models. In our work, we will put the theory of multi-path, which has been proved in [12], into use for the MCMI environment. As expected, performance always improves with increasing number of interfaces. However, the incremental improvement is very small for more than 3 interfaces. Therefore, there are only 2 interfaces and 3 channels per node in our work.

A. Cross-layer model of ACMRV

A cross-layer approach to network design seeks to enhance the performance of a system by jointly considering the information from different layers. This approach allows some layers using the information from other layers to make a better strategic decision. In the ACMRV, both the packet queue length from PHY layer and the available bandwidth calculated from MAC layer are very important information. Packet queue length reflects traffic load in a way, while available bandwidth reflects the quality of networks. ACMRV assignment depends on both of them to select a better channel for forwarding packets and added redundant packets of adaptive FEC.

According to [13, 14], the delay model, a node uses the channel access time of its current traffic to calculate the available bandwidth of a new flow. Figure 2 shows the stages in the transmission of a single packet using the IEEE 802.11 DCF MAC protocol. Node A sends RTS (request to send) to the receiver (AP), Node B who is reachable from A updates its NAV. The idle time in the wireless network can be estimated from the NAV information as a result.

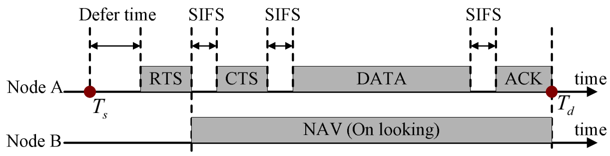

Figure 2. IEEE 802.11 unicast packet transmission.

Let C be the capacity of the wireless network. Then the available bandwidth (AB) can be obtained by the formula 1, where *m* is the number of sending packets in the interval, *n* is the number of being Onlooker, T_d , T_s , OT is the time of receiving packet, packet ready and on looking respectively.

$$AB = C \times (1 - \frac{\sum_{i=1}^{m}(T_{di} - T_{si}) + \sum_{j=1}^{n} OT_j}{\text{total elapsed time}}) \quad (1)$$

Hence, we can get AB after a short period of time from MAC. Figure 3 shows a block diagram of ACMRV model for MCMI wireless networks. There is an ACMRV assignment combining the information of packet queue length and AB to give the best advice to CA and FEC mechanism. This extends the achievable capacity region of the network and can greatly improve the quality of received real-time video. Based on this intelligent CA, each node can select a better channel for forward packets, which can make throughput higher and reduce packet loss ratio.

AB and the information of packet queue length can be considered to adjust how many redundant FEC packets should be generated. In this way, packet transmission can be more efficient under adaptive FEC mechanism.

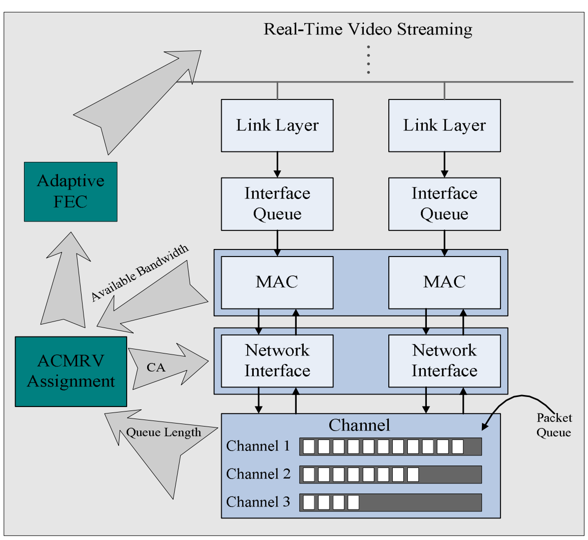

Figure 3. ACMRV model for MCMI wireless networks.

B. Channel assignment of ACMRV

In our work, the CA of ACMRV is implemented according to [7]. In a MCMI wireless network, M interfaces available at each node, which are divided into two groups:

1. Fixed Interface: K of the M interfaces at each node are converted to K channels for long intervals of time. The corresponding channels are regarded as fixed channels while the fixed interfaces are used to receive data and to be switched based on the number of nodes using a channel.

2. Switchable Interface: The remaining M-K interfaces are dynamically assigned to any of the remaining M-K channels over short time scales based on data traffic. The corresponding channels are designated as switchable channels. A switchable interface enables node X to transmit to node Y in its neighborhood by switching to the fixed channel used by Y.

What's more, there are two tables maintained by each node:

1. NeighbourTable (NT): Contains the fixed channels being used by its neighbors.

2. ChannelUsageList (CUL): Keeps the number of nodes using each channel as their fixed channel, but it only tracks the nodes present within its communication range.

We can get the number of nodes using each channel as their fixed channel by checking CUL. If one channel has the largest usage, then the network is not fully utilized, as the most data flows via this fixed channel. To solve this problem, we provide an affect factor (AF) shown by the formula 2, where AB is available bandwidth, qmean is packet queue length's meanvalue in a short previous period, q_current is current queue length, α is a revise factor. Therefore, the AF is larger, the channel condition is better, and we can select a better channel as fixed channel with AF.

$$AF = \frac{AB \times qmean}{\alpha \times |q\_current - qmean| \times q\_current} \quad (2)$$

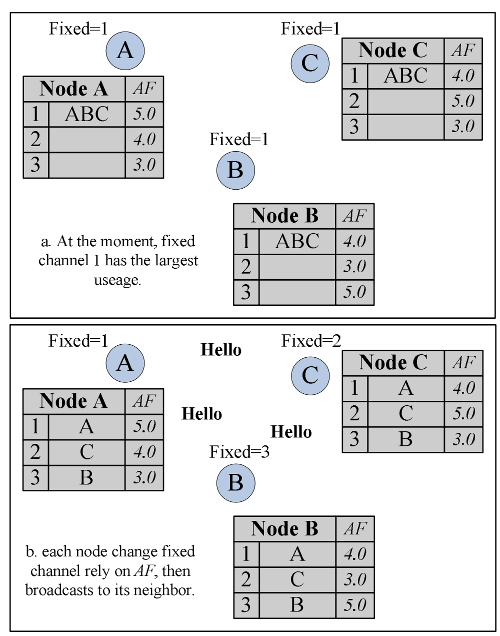

Figure 4. Select fixed channel rely on AF.

In fig. 4(a), there are three nodes that can listen to each other, and their fixed channel is the same channel 1. Each node broadcasts a Hello or Route Discovery packet on every channel, which contains the fixed channel used by the node. When a node receives a Hello or Route Discovery packet from its neighbor, it updates the CUL of itself. At the moment, since channel 1 has the largest usage in this area, every node checks its AF per channel and converts to the channel that has the largest AF. Then, node A doesn't change its fixed channel, node B changes to channel 3, and node C changes to channel 2. In fig. 4(b), after changing the fixed channel, they update their CUL through a Hello or Route Discovery packet again.

With this CA method, each node can select a better fixed channel to receive packets, and can make full use of the network bandwidth.

C. *Adaptive FEC of ACMRV*

FEC is a technique that allows for near perfect data transmission accuracy even when faced with a noisy transmission channel. A number of FEC algorithms are being used including Hamming code, Reed-Solomon code and Bose-Chandhuri-Hocquenghem code. However, in wireless environment, how many redundant FEC packets should be generated is a critical issue, since too many redundant FEC packets may make traffic more crowded in badly current network condition. We make the node dynamically add redundant FEC packets if it really needs. In ACMRV adaptive FEC, packet queue length is a good indicator for estimating network traffic load. For example, the network load is high so that the queue length is long; otherwise, the queue length is short. When queue length is too long in a way, fewer FEC packets should be generated to avoid unnecessary network congestion. What's more, AB is a good way to indicate the quality of networks. The wider AB is, the more redundant FEC packets will be generated.

```
qlen = 0; AB = 0;     // Initialization
/* When a block of packets are received */
qlen := ( | q_current — qmean | × q_current ) / qmean;
if (qlen < threshold1 && AB >threshold4) then no_FEC := Max_FEC;
else if (qlen < threshold1 && AB < threshold3) then
no_FEC := Max_FEC × (threshold3 — AB ) / (threshold4 — threshold3);
else if (qlen > threshold2 && AB < threshold3) then no_FEC := 0;
else if (qlen > threshold2 && AB > threshold4) then
no_FEC := Max_FEC × (qlen — threshold2) / (threshold2 — threshold1);
else no_FEC := standard_no_FEC;
```

Figure 5. Adaptive FEC algorithm of ACMRV pseudocode

Our adaptive FEC algorithm of ACMRV is shown in figure 5. When a block of packets are received, the node calculates queue length (*qlen*) with its meanvalue in a short previous period (*qmean*) and current queue length (*q_current*). After the node gets AB, calculated by the informations from MAC layer, it compares queue length with *AB* and threshold values. If queue length is smaller than low_len_threshold value (threshold1) while *AB* is larger than high_ab_value (threshold4), the maximum FEC packets can be generated. If *qlen* is larger than high_len_threshold value (threshold2) while *AB* is smaller than low_ab_value (threshold3), none FEC packets will be generated. If *qlen* is between threshold1 and threshold2, while *AB* is between threshold3 and threshold4, there will be standard numbers of FEC packets generated. Otherwise, FEC packets are generated based on queue length, *AB* and all threshold values.

IV. SIMULATION EXPERIMENTS

To evaluate the performance of the proposed protocol in MCMI wireless networks, we extend the model in [15] and first compare the single-channel model with original AODV, MCMI model with Pradeep Kyasanura's routing and CA [7] and MCMI model with our ACMRV on the condition of different speed of nodes. Then we compare the quality and peak signal to noise ratio (PSNR) of a real-time video via ACMRV with static FEC, while without CA.

The simulation environment is 1000×1000 square meters, where 16 nodes are randomly distributed. Node pairs are randomly selected to generate CBR/UDP traffic. The random moving radius per node is 100m, and the random moving speed is 0, 5, 10, 15, 25m/s. The path loss model is Two-Ray Ground Model while the CBR data packet size is 1000 bytes. Besides, each node has 2 interfaces and 3 channels and revise factor α is 1.5. What's more, the video traffic trace we use for the experiment is "Bus" video using H.264 video coding with JM 1.7 codec. The "Bus" format is QCIF and the GOP structure is IPPPPPPPPPPPPPP (Simple Profile). Bus video trace is composed of 296 frames, with each frame divided into transmitting slices.

Figure 6 compares the flow throughput of a one channel network with that of a MCMI network using the Pradeep Kyasanura's routing and CA, and that of a MCMI network using our proposed ACMRV. The larger the moving speed per node is, the greater the possibility of breaking the link will be. Therefore, the throughput improvement depends on the underlying topology. In addition, throughput reduces when moving speed of nodes become larger. Throughput of MCMI model is greatly larger than that of SCSI model since multi-channel has greater bandwidth, and ACMRV is better than Pradeep's proposal no matter how much the node speed is. ACMRV can intelligently choose suited fixed channel and better use network bandwidth, making throughput have a great improvement.

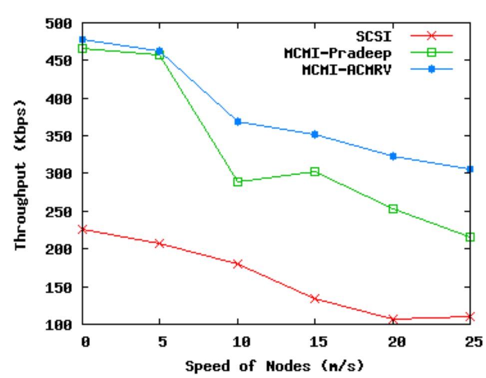

Figure 6. Speed of nodes vs Throughput.

Figure 7 compares the end-to-end delay of a one channel network with that of a MCMI network using the Pradeep Kyasanura's routing and CA, and that of a MCMI network using our proposed ACMRV. Although when the maximum speed of node is 20m/s, the delay of SCSI model is shorter than that of MCMI model, thus overall delay of single channel is longer than that of multi-channel. According to the results, there is a little difference in end-to-end delay between using ACMRV and using Kyasanura's proposal. For the real-time video streaming, they can both work well.

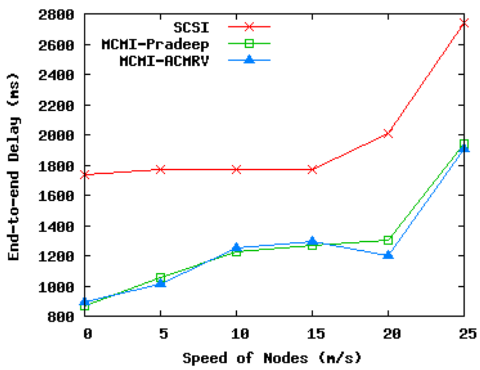

Figure 7. Speed of nodes vs End-to-end delay.

We compare the flow throughput and the end-to-end delay in the network topology in which all nodes are random moving and the maximum speed per node is 25m/s. All nodes are in motion all the time from the beginning of simulation, and the nodes' moving speed is a uniform random number under 25. Figure 8 shows the comparison of throughput for SCSI, MCMI-Pradeep and our proposal. The result shows ACMRV can greatly increase throughput in wireless networks, especially for some mobility environment. It can better utilize every channel to transmit packets.

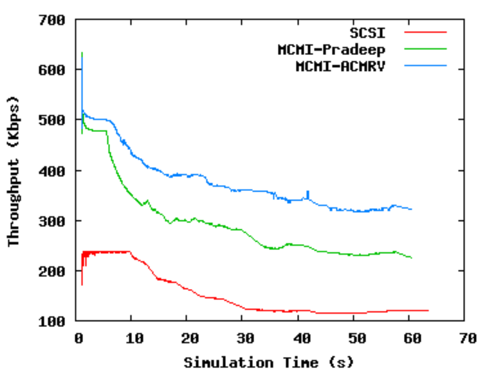

Figure 8. Comparison of throughput

The network topology is changing very rapidly, as shown in figure 9, the end-to-end delay of each packet is also changed largely. To make the observation more convenient, we choose part of the packets to make a comparison. Obviously, the end-to-end delay of the single channel is much higher than that of multi-channel, and some have even over 20s. In Figure 9, by comparing the end-to-end delay of using ACMRV with using Kyasanura's proposal, we know that there is little difference between them, which means in the premise of a better throughput and the end-to-end delay has little increase.

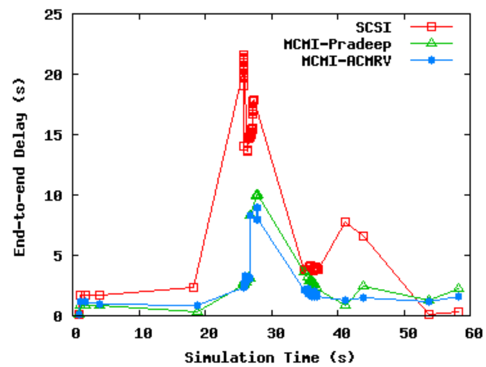

Figure 9. Comparison of end-to-end delay

The received video quality is measured in terms of PSNR. Figure 10 compares the PSNR per video frame using static FEC with adaptive FEC of ACMRV. When some frames' PSNR is low, PSNR with ACMRV is greater than static FEC, so the definition of these frames is better by using ACMRV. 30-120 frames and 160-180 frames have greater difference between two models. ACMRV can be better error correction.

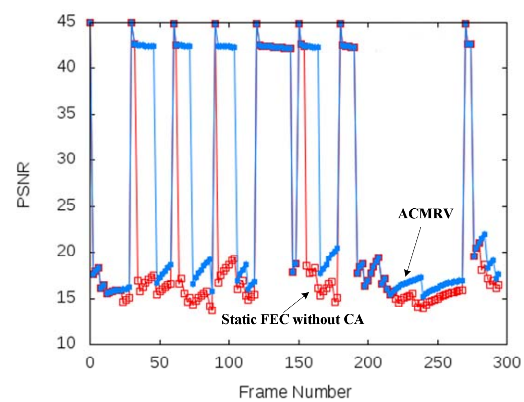

Figure 10. PSNR performance of video streaming for two different model

To better compare the video by using two different models, we use myEvalvid-NT [17] to evaluate the performance of video quality delivery in a simulated network environment. Based on NS-2 environment, myEvalvid-NT evaluates end-to-end video quality using original networks trace, the information of sender trace and the information of receiver trace. Figure 11 shows a same frame by using different model. We can see the markedly difference from the red circle, the quality of video with ACMRV is greatly improved and is better than static FEC. Therefore, ACMRV is a very good model in the real-time video transmission, and can ensure the quality of the video as much as possible.

Figure 11. Original Video (left), Static FEC without CA (middle) and ACMRV (right)

V. Conclusion and Future Works

In this paper, we proposed an adaptive cross-layer mechanism which includes both an efficient CA and an adaptive FEC for real-time video streaming (ACMRV) used in this scenario, on condition that we jointly consider three layers of the protocol stack: the application, data link and physical layers. The simulation based on the proposed architecture via NS-2 shows that the real-time video quality over MCMI wireless networks can be greatly improved by our proposed method.

In our future works, we will consider the effects of SNR from PHY layer and better control fixed channel in MCMI environment. Besides, the optimum algorithm of CA in MCMI situation is also an important research issue in the coming years. We will continue to explore the method to arrange channels in MCMI situations more efficiently.

Acknowledgment

This research was supported in part by the National Natural Science Foundation of China under Grant No.60970019 and No. 60902037, the Hubei Provincial Natural Science Foundation of China under Grant No.2009CDA132, the Fundamental Research Funds for the Central Universities (2010-II-004) and the National Ministry of Education Program of China under Grant No.091049734.

During the building of MCMI simulation platform, many thanks for the exchanges with PhD student Fawaz Bokhari at University of Texas Arlington (US), assistant professor Ramon A.C at University of Cantabria (Spain) and Research Assistant M Ejaz Ahmed at IP Technology Centre of Excellence Lab (Pakistan).

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