CSMA/CA, the Channel Access Mechanism for Reducing Congestion in Wireless Cellular Networks

Regitha M R

Department of Computer Science, Sacred Heart College, Thevara

(Guide:Dr. Varghese Paul, Department of Information Technology, Cochin University of Science & Technology, Thrikkakara)

regitha.baiju@gmail.com

Abstract

While the demand for wireless cellular services continues to increase, radio resources remain scarce. As a result, network operators have to competently manage these resources in order to increase the efficiency of their Wireless Cellular Networks (WCN) and meet the Quality of Service (QoS) of different users. A key component of Radio Resource Management (RRM) is congestion control. Congestion can severely degrade the performance of WCN and affect the satisfaction of the users and the obtained revenues. Several congestion control techniques have been proposed for WCN. These techniques, however, do not provide incentives to the users to use the wireless network rationally, and hence they cannot solve the problem of congestion.In this paper, we recommend a multiple channel access mechanism using CSMA/CA[6] for reducing congestion in WCN.

Keywords **- Wireless Cellular Networks[1], Quality of Service, Digital Data Cellular Networks, Cyclic Polling, Channel Splitting, Reservation, Co-channel Interference, Handover**

1. INTRODUCTION

Congestion control in wireless networks has been extensively investigated over the years and several schemes and techniques have been developed, all with the aim of improving performance in wireless network. With the rapid expansion and implementation of wireless technology it is essential that the congestion control problem be solved.

An important issue in a packet-switched network is congestion. Congestion in a network may occur if the number of packets sent to the network is greater than the number of packets the network can handle. Congestion control refers to the mechanisms and techniques to control the congestion and keep the load below the capacity.

Congestion happens in any system that involves waiting. It occurs because routers and switches have queues-buffers that hold the packets before and after processing. A router has an input queue and an output queue for each interface. When a packet arrives at the incoming interface, it undergoes three steps before departing.

1. The packet is put at the end of the input queue while waiting to be checked.

2. The processing module of the router removes the packet from the input queue once it reaches the front of the queue and uses its routing table and the destination address to find the route.

3. The packet is put in the appropriate output queue and waits its turn to be sent.

2. CELLULAR NETWORK

A cellular network[1] is a radio network distributed over land through cells where each cell includes a fixed location transceiver known as base station. These cells together provide radio coverage over larger geographical areas. User equipment, such as mobile phone, is therefore able to communicate even if the equipment is moving through cells during transmission.

2.1 Elements of a Cellular Network:

Fig. 1 shows the elements of a Cellular Networks:

1. Mobile Station (MS): This is basically the mobile phone.

2. Base Station (BS): The covered area of a cellular network is divided into smaller areas called cells. Each cell has a base station which communicates simultaneously with all mobiles within the cell, and

passes traffic to the Mobile Switching Centre. The base station is connected to the mobile phone via a radio interface.

3. Mobile Switching Centre (MSC): This controls a number of cells (or cluster), arranges base stations and channels for the mobiles and handles connections.

4. National Carrier Exchange: This is the gateway to the national fixed public switched telephone network (PSTN). It handles connections on behalf of the national communication systems, and is usually integrated with the MSC.

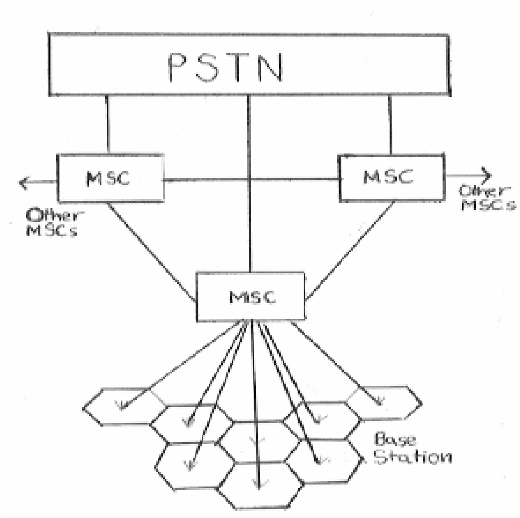

Fig. 1 Elements of Cellular Network

2.2 Operation of the Cellular Phone:

When the mobile unit is active, it registers[2] with the appropriate BS , depending on its location, and its cell position is stored at the responsible MSC. When a call is set-up (when a user makes a call), the base station monitors the quality of the signal for the duration of the call, and reports that to the controlling MSC, which in turn makes decisions concerning the routing of the call.

When a cellular phone moves from one cell to the other, the BS will detect this from the signal power and inform the MSC of that. The MSC will then switch the control of the call to the BS of the new cell, where the phone is located. This is called handover. It normally takes up to 400ms, which is not noticeable for voice transmission.

A cellular phone user can only use his/her mobile within the covered area of the network. Roaming is the capacity of a cellular phone, registered on one system, to be able to enter and use other systems. Those other systems must be compatible to enable. In Europe, the standard cellular network is called GSM (Global System for Mobile Communication). Incoming calls to GSM[8] users are routed to them, irrespective of where they are, as long as they are within Europe.

By assigning a subset of the total number of channels available to each base station,frequency re-use[3] is achieved and controlling the power output of the transmitters. In this way, cellular network increases capacity (number of channels available to users). Interference between the cells occurs because adjacent cells are not allowed to operate at the same frequency. In this way, number of cells in the covered area (i.e. by decreasing the cell size) would increase the capacity. But by doing so, a number of difficulties arise:

- Interference: Decreasing the cell size increases the problems of interference between cells which are using the same frequency.

- Handovers: Decreasing the cell size increases the frequency of handovers, since a moving cellular phone would be changing cells more often. Since the MSC needs time to switch (for handovers), increasing the handovers will increase that time delay.

3. DIGITAL DATA CELLULAR NETWORK[3] MODEL

This model is used for transmitting small chunks of data, commonly referred to as packets, over the cellular network in a reliable manner. It allows users to send and receive data from anywhere in the cellular coverage area at any time, quickly and efficiently. It provides extensive, high speed, high capacity, cost effective data services to mobile users. With this technology, both voice and data can be transmitted over existing cellular channels. The Fig. 2 shows the performance of the cellular network in transmitting data would be based on this cellular network model.

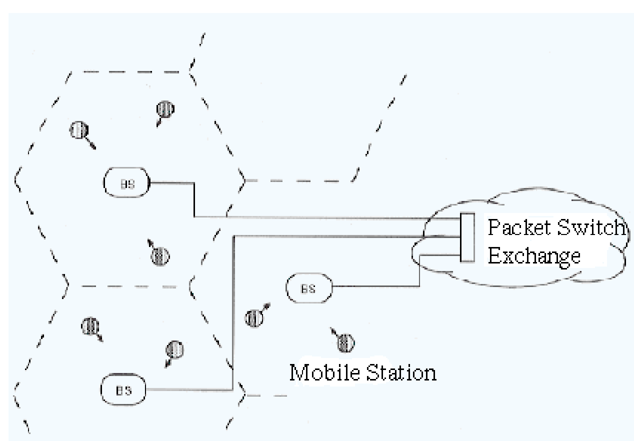

Fig. 2 Digital Data Cellular Network Model

4. BUFFERING[5]

Once handover occurs, the MS and the BS stops transmitting data. However, both of them will still be receiving data from the data terminal and the PSTN network respectively. Therefore the buffer needs to be implemented in two places. One is between the data terminal and the MS for upward transmission (transmission from MS to BS) and the other is between the BSC and the BTC for downward transmission (opposite to upward).

4.1 Buffer Administration Technique:

The MS and the BS receive and transmit data packets. If the MS has only one receiver, it can only tune into one channel at a time and receive a single packet from this channel time slot. So, the packets that arrive at the base station from the packet switch exchange meant for several MSs, have to be queued and forwarded one at a time to the appropriate transmitting channel (channel which the MS is waiting to receive the packets from). Transmitting more than a single packet to a mobile station would result in packet overlap and thus packet loss.

Buffer administration Techniques describes how the arriving packets are queued and selected to be transmitted from the BS to the appropriate MS.There are three Buffer Administration Techniques:-

- Cyclic Polling
- Channel Splitting
- Reservation

4.1.1 Cyclic Polling:

This technique contains an arbitrary number of queues of fixed capacity. Each MS has its own queue that is not shared with other MS. This technique consists of a single server and several numbers of transmitters. Steps of this technique are given below.

1. Check the queue for any packet.
2. If there are, then send the packet to a free transmitter
3. If there are no packets, then move to the next queue
4. repeat steps 1 to 3 until the one of the following conditions
   a. all the queues have been visited
   b. there are no free transmitters

Fig. 3 illustrates the this technique

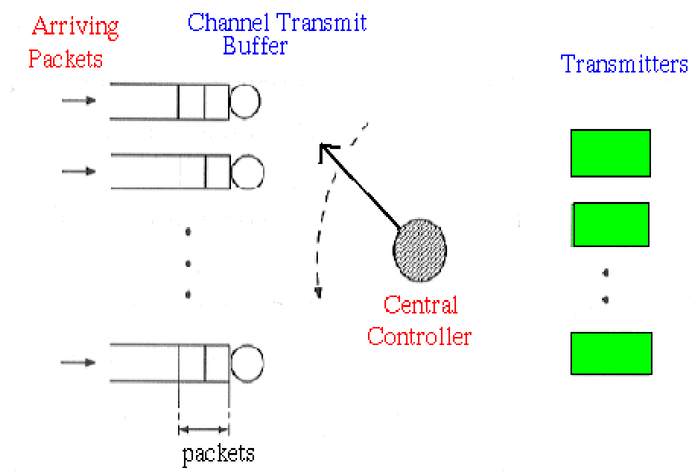

Fig. 3 Cyclic Polling

4.1.2 Channel Split Technique:

This technique is similar to Cyclic Polling Technique but it has several channel controllers which operate in parallel.There are several groups each consists of several queues. Each channel controller is dedicated to each group. The group of queues has its own dedicated transmitter. Packets queued in a group can only be transmitted using this group's transmitter. Fig. 4 displays the operations of this technique.

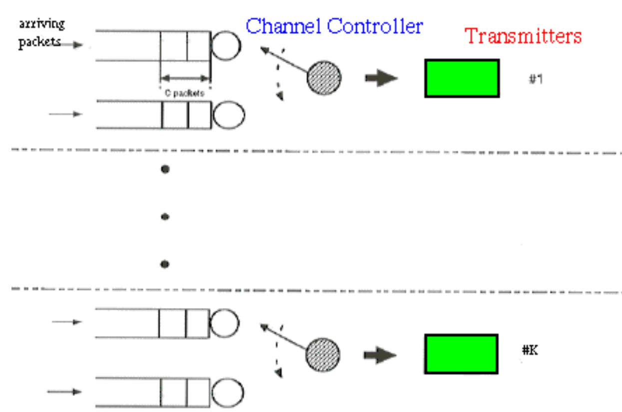

Fig. 4 Channel Split Technique

The steps performed by the channel controller still remains the same as cyclic polling but now it only visits the queues in its group.

4.1.3 Reservation Technique:

In this technique, similar to the Channel Split Technique, the transmitters are dedicated to groups. But now, in each group there is only a single queue. The incoming stream of packets which would have been put into different queues within a group in the Channel Splitting Technique would be put into this single queue. Therefore the queue capacity in this technique is normally multiples of the queue capacity in both Channel and Cyclic Polling Techniques. Fig. 5 shows the operations of Reservation Technique.

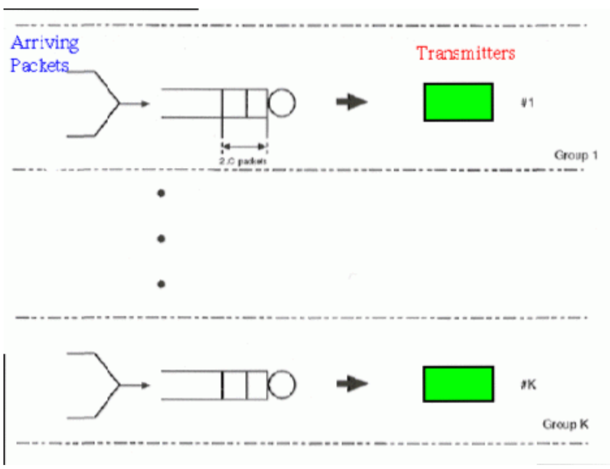

Fig. 5 Reservation Technique

5. http://www.doc.ic.ac.uk/~nd/surprise_96/journal/vol4/fjf/report.html - contentsPERFORMANCE OF THE DIGITAL DATA CELLULAR NETWORK

The Digital Data Cellular Network has many limitations which affects its performance in transmitting data. This includes congestion at the base station, fading, breaks during handovers and co-channel interference. More emphasis is placed on the congestion limitation as it depends on the design of the cellular system. On the other hand the other limitations, such as fading and co-channel interference depend mostly on the nature of the radio signal.

6. CONGESTION

Congestion is said to occur at a BS when it does not have enough space in its queues to put the new arriving packets. These new packets would then be lost. Congestion leads to the packets already in the queue to wait the longest time before being transmitted. So, congestion introduces unacceptable packet delay. The concept of Congestion is given below.

The congestion problem cannot be completely avoided but it can be minimized by

1. Choosing the correct buffer administration technique. This reduces congestion at the BS transmit buffer.

2. Reducing the rate at which BS informs MS to transmit data. This reduces congestion at the BS receive buffer.

3. Increasing the number of channels per cell. Doing this reduces congestion at both the receiving and transmitting buffers of the BS

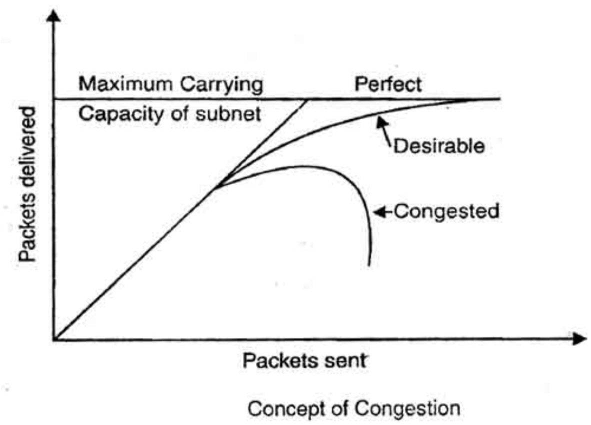

Fig. 6 Concept of Congestion

6.1 Choosing the Best Buffer Administration Technique:

A large rate of packet can arrive without any queue overflow in the best technique. It should also cause minimal congestion when both large and moderate amount of packets arrive. Therefore in order to identify the best technique, the different techniques discussed are compared with respect to the

- maximum arrival rate it supports
- its performance at moderate and high incoming traffic levels

6.1.1 Maximum Rate of Packet Arrival Supported:

The maximum packet arrival rate supported is the maximum rate at which the packets can arrive without any increase in the number of packets stored in the multi-level transmit queue.This occurs when the base station is operating at a steady state where the average number of arrivals in the system is less than the maximum number of departures during a time slot.

When the base station stops operating in the steady state, the amount of free queue space decreases and would eventually lead to queue overflow. This leads to congestion.

6.1.2 Incoming Traffic Level Supported:

The BS is said to support an incoming traffic level when it can operate without any queue overflow and the packets queued has acceptable mean waiting time in the queue.The incoming traffic level considered here can be divided into moderate and high levels. Mathematical analysis[3] shows that the results obtained for both moderate and high incoming traffic levels are the same.

The Reservation Technique gives the best support for both traffic levels without any possibility of queue overflow. The Cyclic Polling Technique gives the second best support followed by the Channel Splitting Technique.

6.1.2.1 Reducing Congestion by the Improved Administration Techniques:

In the techniques described above both the queue size and the number of transmitter channel allocated does not change. These are two main points that are improved upon below.

6.1.2.1.1Dynamic Changes in the Queue Size:

The queue size is changed depending on the rate of packet arrival to the queue. In all three, techniques this would lead to reduction in queue overflow. The queue with a higher rate or number of packet arrival should be allocated a larger queue space. This could be obtained from the queues with lower rate or number of packet arrival respectively.

In order to do this extra intelligence to monitor the rates and number of packet arrival to all the queues is needed. The system should then be able to predict future arrivals based on the previous data obtained. This system should also be able to determine the optimal queue size needed as increasing the size too much would lead to an increase in the mean waiting time of packets.

6.1.2.1.2Dynamic Channel Assignment[4]:

One of the main reasons packet overflow occurs in both Reservation and Channel Splitting Techniques is because of the limited number of transmitter channels available in each group. So an improvement would be to add intelligence that allocates channels to groups that has higher rate or number of packet arrival.

6.1.2.2 Disadvantages of the Above Improved Methods:

Both dynamic channel and queue size assignment requires extra processing power. This could prove to be very costly to implement.

But on the other hand if these methods give an improvement that is more than proportionate to the cost increase, it would be prudent to implement a queuing system with these improved techniques.

6.2 Rate at which BS Polls MS:

The BS controls the rate at which a MS transmits data since the MS transmits data only if it had been polled to do so in the previous time slot. If the rate is too high the receive buffer for this MS in the BS would be congested. For minimizing this congestion, reducethe rate at which the BS polls the MS to transmit packets in the upward data transfer channel.

6.3 Number of Channels per Cell:

When the number of channels per cell is small, base station congestion is very likely to occur. Increasing the number of channels to solve this problem could be a problem since the bandwidth allocated for uplink and downlink transmission is fixed. Therefore increasing the channel number per cell would cause the channel frequencies used in a cell to be re-used in a closer cell. This increases co-channel interference.Use a microcellular network since it can increase the number of channels per cell without an increase in co-channel interference.

6.3.1 Co-Channel Interference:
One of the major challenges in cellular mobile systems is the reduction of co-channel interference. A few methods which can be considered are

- Increasing the separation distance between the two co-channel cells
- Use of directional antennas at the base station
- Decreasing the antenna heights at the base station.

First methodis not advisable because the system efficiency decreases as the number of frequency-reuse cells increases. Third method is not recommended because the reception level at the mobile unit is weakened. Second method is good, when there is fixed number of frequency-reuse cells. The use of directional antennas results in further reduction of co-channel interference and increase in the channel capacity with increase in traffic.

6.3.2 Handover:
In circuit-switch networks, handover is a major problem,

because the radio link between the MS and the BS which is continuously available is lost. During the time in which the link is lost, both the MS and the BS could be transmitting data which will be lost unless effective buffering is provided.

In Digital Data Cellular Network considered, there is no continuous link between the MS and the BS. Packets are transmitted and received by the MS only after the BS informs it to do so. So, the link between the MS and the BS only lasts for one time slot (time in which a packet can be transmitted and received). Therefore, handover can only

7. MAIN CHANNEL ACCESS MECHANISMS

The main job of the MAC protocol is to regulate the usage of the medium, and this is done through a channel access mechanism. A channel access mechanism is a way to divide the main resource between nodes, the radio channel, by regulating the use of it. It tells each node when it can transmit and when it is expected to receive data. The channel access mechanism is the core of the MAC protocol. In this section, we describe TDMA, CSMA and polling which are the 3 main classes of channel access mechanisms for radio.

7.1 TDMA (Time Division MultipleAccess):

In this technology, a specific node, the base station, has the responsibility to coordinate the nodes of the network. The time on the channel is divided into time slots, which are generally of fixed size. Each node of the network is allocated a certain number of slots where it can transmit. Slots are usually organised in a frame, which is repeated on a regular basis.

The base station specify in the beacon (a management frame)the organisation of the frame. Each node just needs to follow blindly the instruction of the base station. Very often, the frame is organised as downlink (base station to node) and uplink (node to base station) slots, and all the communications go through the base station. A service slot allows a node to request the allocation of a connection, by sending a connection request message in it. In some standards, uplink and downlink frames are different frequencies, and the service slots might also be a separate channel.

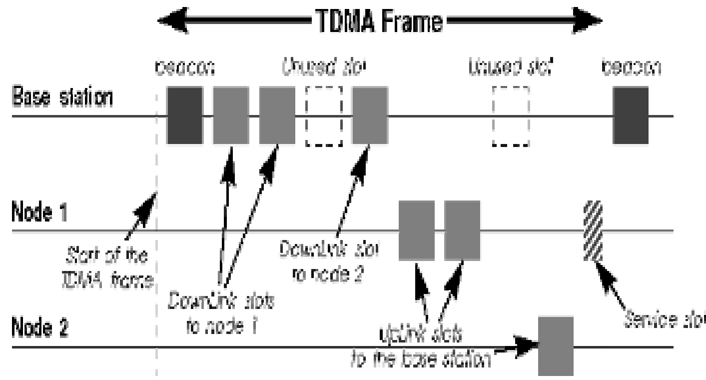

Fig. 7 TDMA Channel Access Mechanism

TDMA suits very well phone applications, because those applications have very predictable needs (fixed and identical bit rate). Each handset is allocated a downlink and an uplink slot of a fixed size (the size of the voice data for the duration of the frame).

7.2CSMA/CA(Carrier Sense Multiple Access/Collision Avoidance)

This channel access mechanism is used by most wireless LANs in the ISM bands. A channel access mechanism is the part of the protocol which specifies how the node uses the medium, when to listen, when to transmit etc.The basic principles of CSMA/CA are, listenbefore talk and contention. This is an asynchronous message passing mechanism (connectionless), delivering a best effort service, but no bandwidth and latency guarantee.Its main advantages are that it is suited for network protocols such as TCP/IP, adapts quite well with the variable condition of traffic and is quite robust against interferences.

CSMA/CA can optionally be supplemented by the exchange of a Request to Send (RTS) packet sent by the sender S, and a Clear to Send (CTS) packet sent by the intended receiver R. Thus alerting all nodes within range of the sender, receiver or both, but not transmit for the duration of the main transmission. This is known as the IEEE 802.11 RTS/CTS exchange. See the Fig. 8

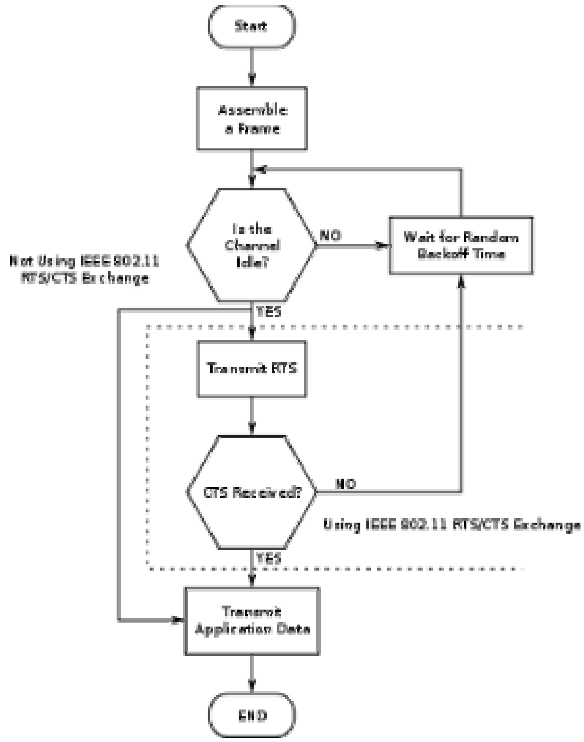

Fig. 8 Simplified Algorithm of CSMA/CA

CSMA/CA is fundamentally different from the channel access mechanism used by cellular phone systems. CSMA/CA is derived from CSMA/CD (Collision Detection), which is the base of Ethernet. The main difference is the collision avoidance on a wire, the transceiver has the ability to listen while transmitting and so to detect. But, even if a radio node could listen on the channel while transmitting, the strength of its own transmissions would mask all other signals on the air. So, the protocol can't directly detect collisions like with Ethernet and only tries to avoid them.

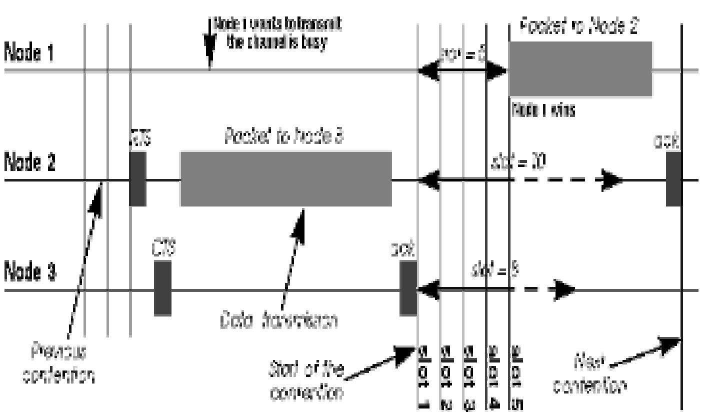

Fig. 9 CSMA/CA Channel Access Mechanism

The protocol starts by listening on the channel and if it is found to be idle, it sends the first packet in the transmit queue. If it is busy, the node waits the end of the current transmission and then starts the contention (wait a random amount of time). When its contention timer expires, if the channel is still idle, the node sends the packet. The node having chosen the shortest contention delay wins and transmits its packet. The other nodes just wait for the next contention (at the end of this packet). Because the contention is a random number and done for every packets, each node is given an equal chance to access the channel.

7.3 Polling MAC:

Polling is in fact in between TDMA and CSMA/CA. The base station retains the total control over the channel, but the frame content is no more fixed, allowing variable size packets to be sent. The base station sends a specific packet (a poll packet) to trigger the transmission by the node. The node just waits to receive a poll packet, and upon reception sends what it has to transmit.

Polling can be implemented as a connection oriented service (very much like TDMA, but with higher flexibility in packet size) or connection less-service (asynchronous packet based). The base station can either poll permanently all the nodes of the network just to check if they have something to send (that is workable only with a very limited number of nodes), or the protocol use reservation slots where each node can request a connection or to transmit a packet (depends on the MAC protocol which is connection oriented or not).

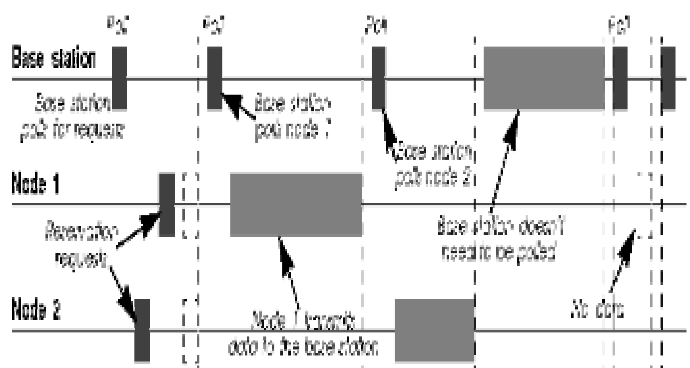

Fig. 10 Polling Channel Access Mechanism

8. CONCLUSION

This paper addresses the Congestion Problem and Congestion Control in WCN. Here, we conclude following points.

1. CSMA/CA gives better packet delivery ratio as compare to TDMA and Polling
2. It minimizes routing overhead as compare to other mechanisms that improve the network performance.
3. Enhanced CSMA/CA and TDMA both provide Collision Free data delivery but Enhanced CSMA/CA better performance through other factors.
4. Enhanced CSMA/CA approach gives better data delivery with minimum data drop rate if actual TCP and UDP packet flow on the network.

Finally we conclude, while the CSMA-CD technique is most used in wired networks, CSMA-CA is the preferred method in wireless networks.

9. REFERENCES

1. Title : Cellular Communications for Data Transmission

   Author : Flack M., Gronow M

   Source : NCC Blackwell Limited. Chapter 1 and 2. Gives a very goodoverview about cellular networks

2. Title : Performance Analysis of Cellular Mobile Communication Systems for Data Transmission

   Author : Wang C.
   Source : IEEE Transactions on Vehicular Technology, Vol. 44, NO.1, 1995
   A detailed analysis of the performance in queuing data in theCD/MD/1/N queue during handover

3. Title : Cellular digital packet data network

   Author : Saha, Debabrata ; Dept. of Electr. Eng. &Comput. Sci., George Washington Univ., Washington, DC, USA ; Kay, S.E.
   Source : Vehicular Technology, IEEE Transactions on (Volume:46 , Issue: 3)

4. Title : Dynamic Channel Assignment in IEEE 802.11 Networks
   Authors : Robert Akl&AnuragArepally

   Source : http://www.cse.unt.edu/~rakl/AA07.pdf

5. Title : Buffer Management in Cellular IP networks

   Author : Mohammad Anbar (Jawaharlal Nehru University, New Delhi) and DeoPrakashVidyarthi (Jawaharlal Nehru University, New Delhi)

   Source : http://www.igi-global.com/article/buffer-management-cellular-network-using/34071

6. Title : Improving Performance for CSMA/CA Based Wireless Networks
   Author : Tianji Li
   Source : http://www.hamilton.ie/publications/Thesis_tianji.pdf