A STUDY OF CONTENTION RESOLUTION SCHEMES FOR IMPROVED QOS OVER IEEE 802.11 DCF

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Table of Contents

1 Wireless Local Area Networks ................................................................. 3
2 Scope of Research ....................................................................................... 4
3 Literature Review ....................................................................................... 5
  3.1 IEEE 802.11 WLANs ............................................................................ 5
     3.1.1 Medium Access Control ................................................................. 6
     3.1.2 Distributed Coordination Function ............................................... 8
4 Compared Schemes ....................................................................................... 10
  4.1 A New Collision Resolution Mechanism to Enhance the Performance of
      IEEE 802.11 DCF ................................................................................. 10
     4.1.1 Basic Idea .................................................................................... 10
     4.1.2 Motivation .................................................................................... 10
     4.1.3 Scheme ....................................................................................... 10
     4.1.4 Results ........................................................................................ 11
     4.1.5 Open Issues ................................................................................. 11
  4.2 A Probability-based Algorithm to Adjust Contention Window in IEEE
      802.11 DCF .......................................................................................... 12
     4.2.1 Basic Idea .................................................................................... 12
     4.2.2 Motivation .................................................................................... 12
     4.2.3 Scheme ....................................................................................... 12
     4.2.4 Results ........................................................................................ 12
     4.2.5 Open Issues ................................................................................. 13
  4.3 SCW: Sliding Contention Window For Efficient Service Differentiation in
      IEEE 802.11 Networks .......................................................................... 14
     4.3.1 Basic Idea .................................................................................... 14
     4.3.2 Motivation .................................................................................... 14
     4.3.3 Scheme ....................................................................................... 14
     4.3.4 Results ........................................................................................ 15
     4.3.5 Open Issues ................................................................................. 16
  4.4 P-DCF: Enhanced Backoff Scheme for the IEEE 802.11 DCF ............. 17
     4.4.1 Basic Idea .................................................................................... 17
     4.4.2 Motivation .................................................................................... 17
     4.4.3 Scheme ....................................................................................... 17
     4.4.4 Results ........................................................................................ 17
     4.4.5 Open Issues ................................................................................. 17
References ....................................................................................................... 19
1 Wireless Local Area Networks

A wireless local area network (LAN) is a flexible data communications system implemented as an extension to, or as an alternative for, a wired LAN. Using radio frequency (RF) technology, wireless LANs transmit and receive data over the air, minimizing the need for wired connections. Thus, wireless LANs combine data connectivity with user mobility.

Wireless LANs have gained strong popularity in a number of vertical markets, including the health-care, retail, manufacturing, warehousing, and academia. These industries have profited from the productivity gains of using hand-held terminals and notebook computers to transmit real-time information to centralized hosts for processing. Today wireless LANs are becoming more widely recognized as a general-purpose connectivity alternative for a broad range of business customers. Business Research Group, a market research firm, predicts a six-fold expansion of the worldwide wireless LAN market in the coming years.

The widespread strategic reliance on networking among competitive businesses and the meteoric growth of the Internet and online services are strong testimonies to the benefits of shared data and shared resources. With wireless LANs, users can access shared information without looking for a place to plug in, and network managers can set up or augment networks without installing or moving wires. Wireless LANs offer the following productivity, convenience, and cost advantages over traditional wired networks:

**Mobility:** Wireless LAN systems can provide LAN users with access to real-time information anywhere in their organization. This mobility supports productivity and service opportunities not possible with wired networks.

**Installation Speed and Simplicity:** Installing a wireless LAN system can be fast and easy and can eliminate the need to pull cable through walls and ceilings.

**Installation Flexibility:** Wireless technology allows the network to go where wire cannot go.

**Reduced Cost-of-Ownership:** While the initial investment required for wireless LAN hardware can be higher than the cost of wired LAN hardware, overall installation expenses and life-cycle
costs can be significantly lower. Long-term cost benefits are greatest in dynamic environments requiring frequent moves, additions, and changes.

**Scalability:** Wireless LAN systems can be configured in a variety of topologies to meet the needs of specific applications and installations. Configurations are easily changed and range from peer-to-peer networks suitable for a small number of users to full infrastructure networks of thousands of users that allow roaming over a broad area.

Thus in short, a Wireless LAN (WLAN) allows user access while on the move within the range of an access point. WLANs are inexpensive and can easily be installed for projects and meeting without any wires. This may be a cost-effective alternative for any government or private entities to expand their existing hardwired computer networks. IEEE has played an important role in the development of WLANs. In 1997 the IEEE standardized IEEE 802.11 wireless local area networks [1]. Today, most WLAN products are based on IEEE 802.11 standard [1]. This standard defines medium access control (MAC) and physical layer protocols for wireless environment. Technology advancements have led to an increase in multimedia applications necessitating time-bounded transfer of data and laying new demands on both wired LAN and WLAN services, making QoS a critical issue. QoS is the capability to provide resource assurance and service differentiation in a network. Motivated by the growing use of multimedia applications, support for time-bounded services was also integrated with IEEE 802.11. This has been achieved by an extension of the basic medium access mechanism (*Distributed Coordination Function* – DCF) using a centralized polling-based mechanism (*Point Coordination Function* – PCF).

## 2 Scope of Research
The changing capacity of wireless link makes it really difficult to provide hard QoS guarantees but a great deal of research is being conducted to give better soft QoS guarantees by efficiently utilizing the available wireless network resources. IEEE has defined 802.11 standard which describes the MAC and PHY characteristics for a WLAN. The basic access mechanism for 802.11 is called DCF (Distributed Coordination Function) which uses a contention based channel access protocol. Normal working of DCF contention window (CW) is that with each collision, the back off window is increased exponentially and with each successful transmission, the CW is decreased to its initial minimum value. Original DCF supports no priorities and its optional counterpart PCF (Point Coordination Function), which was originally designed to support QoS via polling, comes with its problems. As real time applications gained importance, a new standard
802.11e began to emerge that particularly addresses QoS issues in WLAN. However, 802.11e is still in its draft form and its replacement with the widely deployed 802.11 will be costly both in terms of time and money.

As part of this project, we decide to study four backoff schemes/algorithms as proposed in recent years [2,3,4,5] to adjust the contention window in 802.11 DCF in such a way as to provide service differentiation between flows without effecting the original performance of DCF. A one-line description of the four schemes is as follows:

§ Sliding Contention Window (SCW): featuring a sliding contention window for each network flow so that different flows are now able to select backoff intervals from different (separated) CW ranges.
§ Gentle-DCF (GDCF): halving the contention window size after 'c' consecutive successful transmissions.
§ Priority DCF (PDCF): halving the contention window size with a probability 'f' after each successful transmission.
§ Predictive DCF (P-DCF): enables mobile nodes to choose their next backoff times in the collision-free backoff range by continuously listening to the medium.

Simulations will be conducted in OmNeT. These four schemes will be compared among themselves and with legacy DCF in terms of their capability to support QoS, MAC level throughput, delay and packet loss of different priorities and the amount of change required in the original standard to incorporate the new scheme. We will try to take ideas from these schemes and come up with a new Contention Resolution scheme which combines the good points of all.

3 Literature Review

3.1 IEEE 802.11 WLANs
The basic building block of an IEEE 802.11 LAN is the Basic Service Set (BSS). It consists of two of more stations (STA) which communicate through Wireless Medium (WM). These stations are free to move within BSS. A BSS can be categorized into an Infrastructure BSS and an Independent BSS (IBSS). An Infrastructure BSS consists of two or more stations and an Access Point (AP). An AP is usually a centrally located, fixed station with additional capabilities for managing the WLAN. All stations in the BSS are within its transmission range and they communicate to each other or with outside world through AP. The term BSS means infrastructure BSS in this document.
In an IBSS, also called Ad Hoc Network, there is no AP. All stations are within each other’s transmission range and they are able to communicate directly. An IBSS is usually isolated and communication with outside world is not possible. The primary intent is to transfer information among a few, closely located stations.

The geographical size of a BSS is restricted by the limitations caused by the physical layer. However, multiple BSSs can be joined together to form a WLAN of arbitrary size and complexity. The architectural component used to interconnect BSSs is called a Distribution System (DS). Typically a DS is a wired LAN but it can be any communication network. Thus the WM is logically separated from Distribution System Medium (DSM). Stations in a BSS can only send data across the DS via the AP.

![Connecting multiple BSSs via DS](image)

The issue of connecting a WLAN with a wired LAN is resolved with the help of a Portal. A Portal is the logical point at which data from a wired LAN enters the DS. Similarly data from WLAN enters into a wired LAN through portal. Usually portal logic is implemented in a device, such as a bridge, that is part of the wired LAN and that is attached to the DS. It is possible that AP may also act as a portal. This would happen when a DS is implemented from IEEE 802 LAN components.

### 3.1.1 Medium Access Control

The IEEE 802.11 proposes two mechanisms for accessing wireless medium. The first one is distributed in nature and is called Distributed Coordination Function (DCF). The other mechanism is centralized and is known as Point Coordination Function (PCF). Here the term coordination function represents a function that determines when a station is permitted to transmit and receive MAC frames. DCF is mandatory while PCF is optional.
Before explaining these mechanisms, some concepts must be explained. The time interval between two consecutive frames is called Inter Frame Space (IFS). To be more precise, it is the time from the end of the previous frame to the beginning of the subsequent frame. IEEE 802.11 defines four different IFSs to provide priority of access to the wireless medium. The values of these IFSs depend on the Physical layer protocol and are independent of data rate. These are defined below, in increasing order with respect to time duration.

Short Inter Frame Space (SIFS) is the shortest of all IFSs. It is used for an immediate response. For example, an ACK frame in response to a correctly received MAC frame, a CTS frame in response to an RTS frame and a MAC frame in response to a poll frame from AP. SIFS represents the minimum possible time required by a station to generate a response after receiving a MAC frame. Its duration is calculated by considering all the necessary activities that a station must perform before sending a response. These activities include reception of signal at physical layer and its delivery to MAC layer, processing of received message at MAC layer and finally switching from receiving mode to transmitting mode.

\[
\text{SIFS} = \text{Physical Layer Delay} + \text{MAC Processing} + \text{RxTx switching delay}
\]

The important thing to note here is that this response is transmitted without sensing the medium. The protocol ensures that the medium would be idle at that time.

Point Coordination Function IFS (PIFS) is used by the Point Coordinator to access the medium. The duration of PIFS is given by

\[
\text{PIFS} = \text{SIFS} + \text{Slot Time}
\]

where a Slot Time is the minimum possible time required to first sense the medium and then initiate a transmission.

Stations to access the medium in the Contention Period (CP) use distributed Coordination Function IFS (DIFS). DIFS is calculated by using the following relation:

\[
\text{DIFS} = \text{SIFS} + 2 \text{Slot Times}
\]
Extended IFS (EIFS) is used when the last transmission on the medium is considered to be erroneous. If a station finds out that the last frame was corrupted, may be due to the fact that its Frame Check Sequence (FCS) is wrong, it will wait for an EIFS amount of time before attempting to access the medium. The purpose of EIFS is to provide enough time for another station to respond to this frame.

\[
\text{EIFS} = \text{SIFS} + \text{Time required to send an ACK frame} + \text{DIFS}
\]

### 3.1.2 Distributed Coordination Function

The DCF is the basic access mechanism. It employs a Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) algorithm to manage access to the shared medium. When a station wants to transmit, it employs a carrier sense mechanism to find whether the medium is busy or idle. This carrier sense mechanism combines a Virtual and a Physical method to assess the status of medium. The Virtual carrier sense mechanism is provided by MAC layer and is referred to as Network Allocation Vector (NAV). The NAV contains information regarding future traffic on the medium. This information is obtained from the RTS/CTS frames as well as from the duration field of MAC frame header. The Physical layer provides the Physical carrier sense mechanism. After performing this assessment, if the medium is found idle, the station waits for a time period equivalent to DIFS. If during DIFS, the medium remains idle, the station transmits the frame. If the medium is initially busy or it becomes busy during DIFS, the station defers until the end of current transmission and then starts a back off procedure. It randomly chooses an integer between 0 and the current value of Contention Window (CW). This integer is known as the back off value and it represents the number of time slots, which the station must wait before attempting a transmission again. After generating back off value, the station senses the medium again. If it is idle and remains idle for a DIFS (or EIFS, in case when the last transmission on the medium is considered erroneous by this station), the back off value is decremented by one for each time slot the medium remains idle.
This process is continued until either the medium becomes busy again or the back off becomes zero. If the medium becomes busy, the process of decrementing the back off value is stopped. This process is restarted again when the medium is sensed idle for DIFS (or EIFS, in case when the last transmission on the medium is considered erroneous by this station). If the back off value becomes zero, the frame is transmitted.

The receiver immediately acknowledges a successfully transmitted frame after waiting for SIFS, disregard of the busy/idle status of the medium. If the sender does not receive the ACK frame in a certain amount of time, it is assumed that a collision has occurred. Each time a collision occurs, the CW is almost doubled, till it reaches a maximum value ($CW_{max}$). After that the CW remains at this value till it is reset to Contention Window minimum ($CW_{min}$). After adjusting the CW, the back off procedure is run again. If the transmission is successful, the CW is reset to $CW_{min}$ and then the back off procedure is run before sending the next frame. Here, the reason for running the back off procedure again is to reduce the probability of collisions since the collisions will most likely occur at a point where the medium becomes idle immediately after a transmission.

In addition to CW parameter, each station also maintains two other parameters, a Station Short Retry Count (SSRC) and a Station Long Retry Count (SLRC). A MAC frame is considered long if its length is longer than a dot11RTSThreshold. Otherwise it is a short frame. The RTS/CTS frame exchange is used for long frames only. If a transmission attempt fails for a long frame, SLRC is incremented. Similarly SSRC is incremented in case of short frame transmission failure. As stated earlier, the CW value is not increased once it reaches a maximum value ($CW_{max}$). At this point, transmissions failures result in the increase of retry count values and once a limit is reached, no further attempt is made to transmit this MAC frame. It is discarded and the CW is reset to $CW_{min}$. The retry count value is also reset to 0.
4 Compared Schemes

4.1 A New Collision Resolution Mechanism to Enhance the Performance of IEEE 802.11 DCF

4.1.1 Basic Idea
Instead of falling back to $CW_{\text{min}}$ on every successful transmission, CW decrease should follow the same step-by-step approach, as did the CW increase.

- **Stage**
  
  Initial backoff window ($CW_{\text{min}}$) is stage 0. Then after each collision, the backoff stage will be increased by 1, as CW will be doubled.

4.1.2 Motivation
Let us assume that network is under such heavy load and at some large backoff stage ‘i’. Since the current backoff stage is ‘i’, some collisions must have occurred recently. Now if the number of current competing nodes is large and if the backoff stage is reset to 0 after a successful transmission, there is a high probability that some new collision(s) will happen. It is like assuming that current congestion has vanished, which is not the case.

4.1.3 Scheme
GDCF follows an exponential decrease process where the CW is halved following every ‘c’ successful transmissions.

The details of GDCF are as follows, where ‘r’ is the counter for successive successful transmissions:

1. In case of collision, double the CW and reset ‘r’ to 0. Choose backoff uniformly from $[0,\text{CW}]$.
2. In case of successful transmission, if ‘r’ equals ‘c’ then halve the CW and reset ‘r’ to 0. Otherwise leave CW unchanged and just increment ‘r’. Choose backoff uniformly from $[0,\text{CW}]$.
3. In case of idle channel, decrement backoff by 1.
To set parameter ‘c’, the authors have presented detailed probability calculations and simulation results that shows that the short range of 4-8 is optimal value for ‘c’ if the number of competing nodes is greater than 10.

4.1.4 Results

- All the following results are for large number of nodes (>10).
  - For less than 10 nodes, improvements might be subtle or don’t exist at all.
  - For greater than 10 nodes, improvements are independent of number of nodes.
- Optimal value of ‘c’ is between 4 & 8
- GDCF provides 15-20% throughput increase
- GDCF provides better fairness for c>4 than DCF as it makes all competing nodes stay in same backoff stage with high probability. In all cases, fairness is >0.9
- GDCF has smaller RTS failure ratio than DCF for any ‘c’. It decreases further as ‘c’ increases but keeps to a value.
- GDCF drops fewer packets in the MAC level.
- One of the properties in GDCF is that the node with smaller ‘c’ will get the access chances more quickly. We can use this property directly to support QoS differentiation.
- GDCF is very easy to be deployed, as it does not need to estimate a competing node number or change the control message structure and access procedures in DCF.

4.1.5 Open Issues

- Under high network load conditions, backoff stage will oscillate between two large stages ‘i’ and ‘i+1’ with high probability. Will this not cause clustering? And increase collision between flows/nodes of this stage?
- For QoS, though separate flows are now on different stages, higher priority ones on early stages and lower ones on later, still lower priority flows share the initial CW space with higher priority flows. Though with less probability, but they may select a value from the CW of a high priority flow. How bad will it effect the performance?
4.2 A Probability-based Algorithm to Adjust Contention Window in IEEE 802.11 DCF

4.2.1 Basic Idea
Instead of falling back to \( CW_{\text{min}} \) on every successful transmission, \( CW \) decrease should follow the same step-by-step approach, as did the \( CW \) increase

- Stage

  Initial backoff window (\( CW_{\text{min}} \)) is stage 0. Then after each collision, the backoff stage will be increased by 1, as \( CW \) will be doubled.

4.2.2 Motivation
Let us assume that network is under such heavy load and at some large back off stage ‘i’. Since the current backoff stage is ‘i’, some collisions must have occurred recently. Now if the number of current competing nodes is large and if the backoff stage is reset to 0 after a successful transmission, there is a high probability that some new collision(s) will happen. It is like assuming that current congestion has vanished, which is not the case.

![Figure 5 - PDCF Collision Resolution Stage](image)

4.2.3 Scheme
PDCF follows a more conventional approach of halving the contention window size with a probability ‘\( f \)’ alter each successful transmission.

The details of PDCF are as follows:

1. In case of collision, double the \( CW \) and choose backoff uniformly from \([0,CW]\).
2. In case of successful transmission, halve the \( CW \) with a probability ‘\( f \)’. Otherwise leave \( CW \) unchanged with a probability ‘\( 1-f \)’. Choose backoff uniformly from \([0,CW]\).
3. In case of idle channel, decrement backoff by 1.

To set parameter ‘\( f \)’, the authors have presented detailed probability calculations and simulation results that shows that the short range of 0.2 – 0.4 is preferred range for ‘\( f \)’ if the number of competing nodes is greater than 10.

4.2.4 Results
- All the following results are for large number of nodes (>10).
- For less than 10 nodes, improvements might be subtle or don’t exist at all.
- For greater than 10 nodes, improvements are independent of number of nodes.

- Optimal value of ‘f’ is about 0.2 (acceptable range is shown to be 0.2 – 0.4)
- PDCF also provides 15-20% throughput increase
- PDCF provides better fairness than DCF as it makes all competing nodes stay in same backoff stage with high probability. In all cases, fairness is >0.9
- PDCF has smaller RTS failure ratio than DCF for any ‘f’. It decreases further as ‘f’ increases but keeps to a value.
- PDCF can easily extend to support priority application with the flexibility of selecting different ‘f’ values.
- PDCF is very simple to implement and fully compatible with DCF, as it does not need to estimate competing node number or change the control message structure and access procedures in DCF.

### 4.2.5 Open Issues

- In addition to those mentioned of the previous scheme, we have an issue in comparison with the last scheme. All the graphs presented in the paper show f=0.2 to be the optimal value that achieves highest throughput, lowest RTS failure ratio and best fairness. This is only a single value whereas in previous scheme the whole 4-8 range was shown (and proved) to be optimal. For QoS, choosing different values from 4-8 range can support a number of different classes (even real values from this range can be used) but if we use other values of ‘f’ for differentiation, will they not effect the achievable performance? As only 0.2 is optimal and the whole 0.2-0.4 range does not perform quite as well?
4.3 SCW: Sliding Contention Window For Efficient Service Differentiation in IEEE 802.11 Networks

4.3.1 Basic Idea
Ensure more deterministic service differentiation by introducing a sliding contention window (SCW) for each network flow. Different flows are now able to select backoff intervals from different (separated) CW ranges.

4.3.2 Motivation
Although EDCA allows setting different static MAC parameters for each service class, it still does not propose dynamic MAC parameters adaptation according to network condition fluctuations.

Almost all of existing approaches still provide more probabilistic service assurances rather than deterministic one. Particularly, when the network is heavily loaded, though the best effort flows have a large CW, they still can frequently access the medium by randomly selecting short backoff intervals. This scheme controls the backoff randomness through providing strict separation between CW ranges of each traffic class i, j, k, etc.

4.3.3 Scheme
The different flows are now able to select backoff intervals from different (separated) CW ranges. The SCW dynamically adjusts to changing network conditions, but remains within a per-class predefined range, in order to maintain a separation between different

The different sliding CW’s vary dynamically within a per-class defined backoff range, and may overlap to achieve high bandwidth efficiency in every network configuration.

Each traffic class ‘i’ now have an associated sliding contention window SCW [i] which is defined by a lower bound (CW [i] LB) and an upper bound (CW [i] UB). The sliding CW associated to a given TC[i] varies dynamically within a per-TC predefined CW range (CW[i]min, CW[i]max). Each flow’s SCW reacts based on the degree to which class-defined QoS metrics Lr[i] (loss rate) is satisfied. This loss rate is given by LLC/MAC queue and the frames that are discarded. Each time a flow in TC[i] experiences a high loss rate, SCW[i]’s range is increased by a SF[i] step, until the upper bound reaches the maximum window value. When losses are low and packets are transmitted successfully, rather than resetting the contention window, SCW[i]’s range is
decreased with the same SF[i] step, until the lower bound reaches CW[i]min. For service differentiation, the higher TC[i]'s priority, the smaller the sliding factor SF[i]. Lower priorities, such as best-effort traffic, get larger sliding factors.

On the other hand, best-effort traffic does not require any QoS metric thresholds, the contention window must be adjusted slightly differently. We use the instantaneous network load B(T) to adjust the SCW range. B(T) is the fraction of slots that the medium was observed to be busy out of the previous T slots.

So the sliding algorithm becomes.

1. For High Priority Flows
   • If loss rate Lr[i] is greater than and equal to alpha (a threshold value for the maximum tolerated loss rate for TC[i]) then decrease the SCW.
   • If alpha/2 is less than loss rate Lr[i] which is less than alpha then maintain current SCW.
   • If loss rate Lr[i] is less than equal to alpha/2 then increase the SCW.

2. For Best Effort Flows
   • If B(T)/T is less than equal to B(T)threshold then decrease SCW.
   • If B(T)threshold is less than B(T)/T which is less than B(T) saturation then maintain the current SCW.
   • If B(T)/T is greater than equal to B(T)saturation then increase the SCW.

According to authors the best value they found for B(T)threshold and B(T)saturation is 0.7 and 0.9 respectively. Alpha is adjusted depending on the packet loss requirements of the particular flow.

4.3.4 Results

• The high priority flows throughput never falls below a certain value (where as in 802.11 and 802.11e it faces high oscillations). At the same time medium and low priority use residual resources depending on their CWmin.

• CW[i]min is a crucial parameter that significantly affects the performance of SCW regarding the class based QoS separation.

• SCW considerably confines flows throughput oscillation as a consequence of a quite constant inter-frame distance; this is due to a reduced variance between the successive selected backoff values.
4.3.5 Open Issues

- The performance of SCW can drastically change depending on the value of class-specific parameters such as CW[i]min, CW[i]max, and SF[i]. How to assign them in first place?
- How to assign these parameters, to adjust tradeoff between strict service differentiation and increased bandwidth efficiency for every network configuration?
- Sensing medium for load conditions, how to incorporate it in existing 802.11 DCF mechanism?
4.4 **P-DCF: Enhanced Backoff Scheme for the IEEE 802.11 DCF**

4.4.1 **Basic Idea**
P-DCF enables mobile nodes to choose their next backoff times in the collision-free backoff range by continuously listening to the medium.

4.4.2 **Motivation**
The original IEEE 802.11 DCF with the binary exponential backoff mechanism suffers from frequent packet collisions under high traffic load. This is mainly because each mobile node chooses random backoff time independently of each other. Therefore, packet collision probability is high under high traffic load, resulting in throughput degradation. In such an environment, each mobile node can approximately predict others’ transmissions by continuously listening to the medium. Therefore, it is beneficial that they select their backoff time as differently as possible.

4.4.3 **Scheme**
The mobile node calculates the number of idle time slots (ITS) between the prior successful transmission and the current successful transmission. Then, it uniformly chooses its next backoff time in the range $[\text{CW-ITS}, \text{CW}]$. That is, the mobile node predicts that the range $[\text{CW-ITS,CW}]$ doesn’t include others’ backoff times, which reduces packet collision probability.

If the number of idle time slots is very small and many nodes contend with each other, the packet collision probability may be very high. Therefore, we assume that a mobile node adjusts its current contention window depending on the number of competing nodes.

4.4.4 **Results**
- Better throughput up to 17(%) 
- The collision probability for each packet transmission in 802.11 DCF is about 0.25 (4 active nodes/flows). However, by using the proposed P-DCF, we can obtain the packet collision probability near to zero.

4.4.5 **Open Issues**
- How a mobile node adjusts its current contention window depending on the number of competing nodes? Is it implicit by collisions or should there be any explicit mechanism?
- How to adjust contention window in case of collision?
- Simulation results with 4 mobile nodes. What if number of competing stations is increased?
- How to provide service differentiation among traffic categories using transmission history?
- Sensing medium for keeping free slot counts, how to incorporate it in existing 802.11 DCF mechanism?
References


