QoS Issues and Solutions in Wireless Networks

Fethi Filali
Assistant Professor
Institut Eurécom
http://www.eurecom.fr/~filali

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The Global Picture
Advantages and Disadvantages of WLANs

- **Advantages**
  - very flexible within the reception area
  - ad-hoc networks without previous planning are possible
  - (almost) no wiring difficulties (e.g. historic buildings, firewalls)
  - more robust against disaster

- **Disadvantages**
  - low bandwidth compared to wired LANs
  - many proprietary solutions, especially for higher bitrates,
  - standards take their time (e.g. IEEE 802.11)
  - national restrictions for working wireless, it takes long time to establish global solutions
QoS in 802.11-based wireless networks

- **In infrastructure WLAN:**
  - all hosts are associated to a single access point
  - supporting QoS at the MAC layer
    - possibility to have a centralized QoS MAC mechanism
    - a service **“close to” hard-QoS** could be (at least *theatrically*) provided
  - supporting QoS at the IP layer
    - IP QoS architectures proposed for wired networks could be used
QoS in 802.11-based wireless networks

- In ad hoc WLAN:
  - nodes act both as terminals and routers
  - no centralized entity
  - supporting QoS at the MAC layer
    - distributed MAC access mechanism
    - difficulty to implement a reservation-based MAC
    - difficulty to provide hard QoS guarantees
  - supporting QoS at the IP layer
    - service differentiation
    - QoS-based routing
    - BUT: mobility increases the complexity and reduce performance of IP QoS standard approaches
QoS Support in 802.11e MAC Layer
Problems with Existing MAC Mechanisms

- **Problems with DCF to support QoS**
  - Unbounded delays and jitters
  - Bandwidth wastage (Max. 73.5%)
  - Client station misbehavior
  - **No differentiation** of station’s data traffic

- **Problems with PCF to support QoS**
  - No polling differentiation
  - Uncontrollable hidden stations
  - Unpredictable beacon frame delay
  - Unknown transmission time of polled stations
  - Incomplete implementation
QoS Support Mechanism of 802.11e

- 802.11e introduces the Hybrid Coordination Function (HCF) for QoS Support
- HCF defines two medium access mechanisms:
  - Contention-based channel access: Enhanced Distributed Channel Access (EDCA)
  - Controlled channel access (including polling): HCF controlled channel access (HCCA)
- EDCA is used in the Contention Period phase
- HCCA is used in both phases: Contention Period (CP) and Contention Free Period (CFP)
- The HCF combines method of the PCF and DCF (the reason it is called hybrid)
QoS Support Mechanism of 802.11e

- An 802.11e station that obtains medium access must not utilize radio resources for a duration longer than a specified limit: **Transmission opportunity (TXOP)**

- **TXOP:**
  - An interval of time when an STA has the right to initiate transmissions
  - Defined by a starting time and a maximum duration
  - TXOPs obtained via *contention-based medium access* are referred to as **EDCA-TXOPs**
  - A TXOP obtained via *controlled medium access* are referred to as **HCCA-TXOP** or polled TXOP
  - The duration of an EDCA-TXOP is limited by **TXOPlimit** distributed regularly by the **HC**
The QoS support in EDCA is provided by the introduction of Access Categories (ACs).

4 different ACs within one station:
- AC_VO: voice
- AC_VI: video
- AC_BE: best effort
- AC_BK: background

Each AC has its own parameter set defined by the EDCA:
- Interframe spacing: Arbitration Inter-Frame Space (AIFS), etc.
- Contention windows: CWmin, CWmax
## Access Categories in 802.11e

<table>
<thead>
<tr>
<th>Priority (Same as 802.1D Priority)</th>
<th>802.1D Designation</th>
<th>Access Category (AC)</th>
<th>Designation (Informative)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BK</td>
<td>0</td>
<td>Best Effort</td>
</tr>
<tr>
<td>2</td>
<td>-</td>
<td>0</td>
<td>Best Effort</td>
</tr>
<tr>
<td>0</td>
<td>BE</td>
<td>0</td>
<td>Best Effort</td>
</tr>
<tr>
<td>3</td>
<td>EE</td>
<td>1</td>
<td>Video Probe</td>
</tr>
<tr>
<td>4</td>
<td>CL</td>
<td>2</td>
<td>Video</td>
</tr>
<tr>
<td>5</td>
<td>VI</td>
<td>2</td>
<td>Video</td>
</tr>
<tr>
<td>6</td>
<td>VO</td>
<td>3</td>
<td>Voice</td>
</tr>
<tr>
<td>7</td>
<td>NC</td>
<td>3</td>
<td>Voice</td>
</tr>
</tbody>
</table>

- Priority to Access Category mappings
Legacy 802.11 and 802.11e With Four ACs

- 4 Access Categories (ACs) within one station
- AIFS: Arbitration Inter-Frame Space

Source: MANGOLD 2003
HCF Operations

- The HC defines different parameter values of all ACs.

- These values can be modified over time by the HC, and are announced via information fields in beacon frames.

- The same EDCA parameter set of a AC is used by all stations.

- Each backoff entity (a station’s AC) within a station independently contends for a TXOP:
  - It starts down-counting the backoff-counter after detecting the medium being idle for a duration defined by the AIFS[AC] (and not a DIFS as for legacy stations).
HCF Parameters

- \(\text{AIFS}[\text{AC}] = \text{SIFS} + \text{AIFSN}[\text{AC}] \times \text{aSlotTime}\)
  - \(\text{aSlotTime}\): the duration of a slot
  - \(\text{AIFSN}[\text{AC}] > 2\): \(\text{AIFSN}[\text{AC}]\) should be selected by the HC such as the earliest access time of EDCA stations is DIFS
  - The smaller the \(\text{AIFSN}[\text{AC}]\), the higher the medium access priority

- \(\text{CWmin}[\text{AC}]\): minimum contention window of AC

- \(\text{CWmax}[\text{AC}]\): maximum contention window of AC: the smaller it is the higher the medium access priority

- 802.11e defines a maximum lifetime per MSDU: it can be useful since transmitting a frame too late is not meaningful to real-time applications
HCF Parameters

- **TXOPlimit[AC]** is defined per AC as part of EDCA parameter set: *the larger TXOPlimit[AC] is, the larger the share of capacity for this AC*

- Once a TXOP is obtained using a backoff, an AC may continue to deliver *more than one MSDUs consecutively during the same TXOP*, which may take up to the duration of TXOPlimit[AC]
  - This is referred to as continuation of an EDCA-TXOP

- During a contention, when the **counters** of two ACs at the same station **reach zero at the same time**, a **virtual collision** occurs
HCF – Controlled Medium Access

- **HCCA** allows the highest priority medium access to the HC during the CFP and CP

- A TXOP can be obtained by the HC via **controlled medium access**

- The HC may allocate TXOPs to itself to initiate MSDU deliveries whenever it requires, after detecting the medium as being for PIFS, and **without backoff**

- **During CP**, each TXOP of an 802.11e station begins either:
  - the medium is determined to be available under the EDCA rules
  - Or when a backoff entity receives a polling frame, the QoS CF-Poll, from the HC
HCF – Controlled Medium Access

- **During CFP**
  - The HC polls STAs and give a station the permission to access channel
  - Starting time and maximum duration of each TXOP are specified by HC

- **During CP**
  - HCF can issue polled TXOPs in the CP by sending CF-Poll after a PIFS idle period
  - **Controlled Contention**
    - The HC allows STAs to request the allocation of polled TXOPs
    - STAs send resource request frames with the requested Traffic Category and TXOP duration
    - HCF sends an ACK for resource request to the STA
    - A polled station can transmit multiple frames (separated by SIFS) that the station selects to transmit according to its scheduling algorithm
An example of an 802.11e superframe

- The **HC grants TXOPs** in contention-free period and contention period
802.11e Features - Acknowledgement

- Legacy 802.11: an ACK for each data frame
- 802.11e: two more options
  - No acknowledgment
  - Block acknowledgment:
    - Transmission of several data frames (separated by SIFS) without expecting an ACK (similar to the cumulative acknowledgement of TCP)
    - Block-ACK is negotiated between the QSTA and SAP
    - Immediate block-ACK: at the end of a burst the sender transmits a block-ACK Request frame, the receiver reply with a block ACK frame containing the status of reception
    - Delayed block-ACK: allows acknowledgment to be sent in a subsequent TXOP following the burst
802.11e Features – Direct Communication

- **Legacy 802.11**: stations may only communicate with APs: to enable communication between nodes even if they are out of transmission range of each other.
- **802.11e** enables the data exchange between two stations in an infrastructure network through the Direct Link Protocol.
QoS Support in Wireless IP Layer
MANET Characteristics

- Ad hoc networks are networks:
  - That can be rapidly deployed
  - That do not rely on pre-existing infrastructure
  - Whose set of nodes is continuously changing
  - Which self adapt to the connectivity and propagation patterns
  - Which adapt to the traffic and mobility patterns

- New QoS Metrics:
  - Power consumption
  - Network lifetime, or time to network partition
Main MANET QoS Challenges

1. No Centralized authority for network control, routing or administration

2. Network devices are free to move rapidly and arbitrarily in time and space => route change/ packets loss

3. Resources including energy, bandwidth, processing capacity and memory, that are relatively abundant in wired environments, are strictly limited and must be preserved

4. Effects of multiple access, fading, noise, and interference: time-varying channel capacity => difficult to determine the aggregate bandwidth between two endpoints
Challenges in ad hoc QoS routing

- Admission control
  - Make admission decision with time-varying link capacity
- Resource reservation
  - Guarantee the availability of the reserved bandwidth over shared medium
- End-to-end delay guarantee
  - How to measure end-to-end delay in a unsynchronized network?
  - Delay violation detection
- Route failure detection and recovery
  - Detect route break by lost neighbor - too slow!
  - Any thing better than re-discovery? (AODV, DSR)
- Low control overhead
  - Explicitly releases the reserved resource each time the flow changes its route?
QoS Routing difficulties and Proposals

- Three difficulties to support QoS routing in MANET
  1. Overhead is too **high**
  2. Maintaining the precise link state information is **very difficult**
  3. The reserved resource may **no longer available** because of path breakage

- MANET QoS routing protocols
  - CEDAR (Infocom’99)
  - Ticket based probing (Jsac’99)
  - QoS routing based on bandwidth calculation (Jsac’99)
  - QoS Extensions of AODV (IETF draft 2000)
  - **AQOR (JPDC’03)**
Ad hoc QoS On-demand Routing (AQOR)

- Flat architecture
- Full on-demand (no route caching)
- Hop-by-hop routing
- Neighborhood maintenance
- Per-flow granularity
- Temporary bandwidth reservation
- Existing MAC: IEEE 802.11(e)
- QoS guarantees
  - Minimum bandwidth
  - Maximum end-to-end delay
AQOR Algorithm

Four main steps:

1. Route discovery
2. Admission control
   a. Traffic estimation and bandwidth availability
   b. End-to-end delay estimation
3. Resource reservation
4. Adaptive routing
Phase 1 - Route Discovery

- Route request (RREQ) **flooding from Source including** $B_{\min}$ and $T_{\max}$
- **Admission control** is done at each node before forwarding
- Destination replies **to each request** along the reverse route
- If no data arrives at the **registered** node in in $2*T_{\max}$, it means that the route was not chosen by the source

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Represented links on path taken by RREP
2.a: Traffic estimation and bandwidth availability

- **Traffic category**
  - Self traffic (S,D)
  - Neighbor traffic (B,C)
  - Outgoing traffic (E,F)

- Traffic in wireless is a two-hop concern
  - Hidden-node effect
  - Traffic aggregation

- Neighbor information critical in traffic estimation:
  - Each node periodically broadcasts a HELLO message to its neighbors (TTL=1) **including its self-traffic**
  - Failure to receive a HELLO message from a neighbor for $T_{\text{lost}}$ period is an indication of link breakage
2.a. Available Bandwidth Estimation

- Compute the aggregated bandwidth around node I:
  \[ B_{agg}(I) = B_{self}(I) + B_{neighborhood}(I) + B_{boundary}(I) \]

- Compute the available bandwidth
  \[ B_{available}(I) = B - B_{agg}(I) = B - \sum_{J \in N(I)} B_{self}(J) \]

- \( B_{self}(S) = Lsa + Lsd; \)
- \( B_{self}(A) = Lsa; \)
- \( B_{self}(B) = Lbc; \)
- \( B_{self}(C) = Lbc; \)
- \( B_{self}(D) = Lsd; \)
- \( B_{self}(E) = Lef \)
- \( B_{agg}(S) = Las + Lbc + Lds + Lef \)
2.a. Requested Bandwidth Estimation

- Traffic aggregation of flow forwarding in three sequential hops
- Local topology information
  - Relative position in route from Source to Destination

\[ B_{\text{consumed}}(I, \text{flow}_j) = B_{\text{uplink}(I)}(\text{flow}_j) + B_{\text{downwlink}(I)}(\text{flow}_j) \]
Phase 2.b: End-to-end delay estimation

- Unsynchronized network

- Estimate end-to-end downlink delay by measuring round trip delay $T_{\text{round}}$
  - Symmetric feature of radio channel

- Route established on path where the first in time reply comes
Phase 2.b: End-to-end delay estimation

- **End-to-end delay**
  - $T_{\text{queue}}(i)$: queuing delay at node $i$
  - $T_{\text{trans}}$: packet transmission time from a node, i.e., service time.
  - $T_{\text{prop}}$: route propagation delay between the source and the destination

$$T_{\text{down}}(S \rightarrow D) = \sum_{i} T_{\text{queue}}(i) + T_{\text{trans}} + T_{\text{prop}}$$

$$T_{\text{up}}(D \rightarrow S) = \sum_{i} T_{\text{queue}}(i) + T_{\text{trans}} + T_{\text{prop}}$$

- $T_{\text{diff}} = T_{\text{down}} - T_{\text{up}} = T_{\text{queue}}(S) - T_{\text{queue}}(D)$; independent of specific route
Phase 3: Resource reservation

- Bandwidth reservation by reply/data packet

- Temporary reservation
  - Enable route adaptively to environment changes
  - Maximum packet inter-arrival time:
    \[ T_{\text{interval}} = \frac{(k \times N \times 8)}{B_{\text{min}}} \]
    - \( k \): allowed packet loss
    - \( N \): maximum packet size in byte supported by the PHY
IntServ-like Mechanisms in MANET

- In IntServ-like mechanisms:
  - **Application specifies** traffic and QoS parameters.
  - Given the parameters and a chosen path, a resource reservation protocol estimates and **reserves sufficient resource at each node on the path**

- In a multihop wireless network, however:
  - **It is hard to estimate available resource:**
    - Dynamic bandwidth due to node mobility and random contention
  - **It is hard to do resource reservation:**
    - Shared medium reservation requires **global coordination**
    - Violations can occur as **bandwidth fluctuates due to node mobility**
  - **Resource reservation is pinned to a route:**
    - Must be redone whenever route changes.
DiffServ-like Mechanisms in MANET

- In DiffServ-like mechanisms:
  - Application chooses a class of service
  - Network **needs admission control** to avoid class overload and maintain assurances
  - Examples:
    - Assured Forwarding Per Hop Behavior assures per-hop throughput.
    - Expedited Forwarding Per Hop Behavior assures per-hop low delay.
    - Per Domain Behaviors for end-to-end assurances.

- In a multihop wireless network, however:
  - *It is hard to do admission control:* Flows are **distributed** over the network and **do not go through** common ingress nodes.
  - *It is hard to maintain assurances:* Flow distribution **varies** as routes change. Bandwidth fluctuates.
QoS Alternative Architectures

- No IP QoS
- Classification for each IP packet received by the MAC

**Pros:**
- A simple IP layer: no differentiation at the IP Layer

**Cons:**
- MAC complexity and processing time
QoS Alternative Architectures

- QoS IP: diffserv-like architecture
- One queue at the MAC layer
- **Pros:**
  - A simple MAC layer
  - Use architectures *already developed* for wired networks
- **Cons:**
  - Competition of packets at the MAC layer: *reserved service may be affected*
  - Channel *characteristics are hidden* to the IP layer to ensure a good service differentiation
QoS Alternative Architectures

- IP QoS and MAC QoS are used
- Need of QoS mapping sub-layer

**Pros:**
- end-to-end QoS and point-to-point QoS
- QoS in multi-hop wireless networks

**Cons:**
- high complexity
- no trivial mapping between IP and MAC classes of service
Perhaps the Ideal WLAN QoS Architecture is!

- not fare from the following one
Conclusions

- QoS Issues in GPRS, UMTS, Bluetooth have not been covered

- Supporting QoS at IP level is not trivial in wireless networks due to their inherent characteristics:
  - mobility, packet loss, link breakage, etc.

- A better QoS MAC in MANET could be a hybrid approach

- A big open issue: QoS support in heterogeneous networks