QoS-Aware Cooperative and Opportunistic Scheduling Exploiting Multiuser Diversity for Rate-Adaptive Ad Hoc Networks

Transactions on Vehicular Technology, 2008
Authors: Qing Chen, Qian Zhang, Zhisheng Niu

Presented by Hsi-Min Lin
12/19, 2008
OUTLINE

n INTRODUCTION
n PROBLEM FORMULATION
n OPTIMAL CRITERIA OF SCHEDULING
n HEURISTIC SCHEDULING
n SIMULATION RESULT
n CONCLUSIONs
To achieve **high utilization** of the **scarce** wireless resource.

- **opportunistic transmission**
  - improve the overall network throughput

Two main classes of **opportunistic transmission** in MANET.

- **Exploit time diversity**
  - opportunistic auto-rate (OAR)

- **Exploiting multiuser diversity**
  - opportunistic packet-scheduling and auto-rate (OSAR)
  - **medium-access-diversity (MAD)**
Two examples with two transmitters
INTRODUCTION (3/3)

n Three unique issues for exploiting multiuser diversity in MANETs
   n cochannel interference
   n QoS requirements of each flow
   n estimating the channel conditions
PROBLEM FORMULATION

- The opportunistic scheduling:

\[
\max_Q \sum_{i \in \mathcal{N}} E \left\{ f_i (\mu_i(t)) I_{i \in \mathcal{Q}(t)} \right\} \\
\text{s.t.} \quad E \left\{ g_i (\mu_i(t)) I_{i \in \mathcal{Q}(t)} \right\} \geq G_i \quad \forall i \in \mathcal{N} \\
\quad c(i, j, t) = 0 \quad \forall i, j \in \mathcal{Q}(t), \ i \neq j
\]

- \( \mu_i(t) \): ith flow’s feasible data rate, in timeslot t
- \( f_i (\mu_i(t)) \): utility function
- \( \mathcal{Q}(t) \): scheduled transmitting flow set in timeslot t
- \( c(i, j, t) = 1 \), if flow i and j are edged in \( CG(t) \)
- \( g_i (\mu_i(t)) \): generalized function, use to describe different constraints
- \( G_i \): ith flow’s long-term QoS requirement
OPTIMAL CRITERIA OF SCHEDULING

The flow set selected by optimal scheduling should be a **MIS** (Maximal Independent Subset).

The optimal solution of the opportunistic scheduling:

\[
Q^*(t) = S_{m^*}(t), \quad \text{where}
\]

\[
m^* = \arg \max_m \left\{ \sum_{i \in S_m(t)} [f_i(\mu_i) + \lambda_i g_i(\mu_i)] \right\}
\]

\(\lambda_i\)'s: the Karush–Kuhn–Tucker (KKT) multipliers (ith flow’s QoS factor)
Focus on the **minimum bandwidth constraints** and the **network throughput maximization**

\[ g_i(\mu_i) = f_i(\mu_i) = \mu_i \]

**Optimal criteria**

\[ Q^*(t) = S_{m^*}(t), \quad m^* = \arg \max_m \left\{ \sum_{i \in S_m} \mu_i(1 + \lambda_i) \right\} \]
Cooperative and opportunistic scheduling (COS)

- IEEE 802.11-based
- distributed
- cooperative
- obtains higher network throughput
- better QoS support than the existing schemes
- with limited local information.
## HEURISTIC SCHEDULING

A diagram illustrates the scheduling process involving multiple receivers and phases:

<table>
<thead>
<tr>
<th>DIFS</th>
<th>SIFS</th>
<th>SIFS</th>
<th>SIFS</th>
<th>SIFS</th>
<th>TIFS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>transmitter</strong></td>
<td>GRTS</td>
<td></td>
<td>CTS</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>receiver 1</strong></td>
<td></td>
<td>CTS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>receiver 2</strong></td>
<td></td>
<td></td>
<td>CTS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
<td>...</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>receiver k</strong></td>
<td></td>
<td></td>
<td>CTS</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The timeline progresses through Channel Probing, Credit Calculation, Link Scheduling (Phase I), DATA Transmission, and Link Scheduling (Phase II).
Channel Probing and Information Exchanging

Two-hop transmission-range information exchanging

Local contention graph (LCG)

average LCG

Contended: if and only if one node of a flow is in the two-hop average transmission range of any node of another flow.

Credit table

includes flow’s

identifier

the feasible data rate

the QoS factor

Updates

channel probing mechanism

overhearing other flows’ control packets.
Credit Calculation

CR(X) : credit function which returns the credit of entity X

Two-Transmitter Scenario

{S_m} = \{S_1, S_2, S_3, S_4\} = \{\{F_2\}, \{F_3\}, \{F_1, F_4\}, \{F_1, F_5\}\}
Credit Calculation

A MIS’s credit

\[ CR(S_m) = \sum_{i \in S_m} \mu_i (1 + \lambda_i) \]

Example

\[ \{S_m\} = \{S_1, S_2, S_3, S_4\} = \{\{F_2\}, \{F_3\}, \{F_1,F_4\}, \{F_1,F_5\}\} \]

\[ U_i = \mu_i (1 + \lambda_i) \rightarrow \{2, 4, 5, 4, 5\} \]

\[ CR(S_3) = U_1 + U_4 = 2 + 4 = 6 \]

\[ CR(S_m) \rightarrow \{4, 5, 6, 7\} \]
Credit Calculation

A flow’s credit

\[ CR(l_i) = \max_m \{ CR(S_m) \mid i \in S_m \} \]

Example

\[ \{S_m\} = \{ S_1, S_2, S_3, S_4 \} = \{ \{F_2\}, \{F_3\}, \{F_1, F_4\}, \{F_1, F_5\} \} \]

\[ CR(S_m) \rightarrow \{ 4, 5, 6, 7 \} \]

\[ CR(l_i) = \max \{ CR(S_3), CR(S_4) \} = \max \{ 6, 7 \} = 7 \]

\[ CR(l_i) \rightarrow \{ 7, 4, 5, 6, 7 \} \]
Credit Calculation

- A transmitter’s credit
  \[ CR(T_A) = \max_i \{ CR(l_i) \mid i \text{ is originated by transmitter } A \} \]

Example

\[ \{ S_m \} = \{ S_1, S_2, S_3, S_4 \} = \{ \{ F_2 \}, \{ F_3 \}, \{ F_1, F_4 \}, \{ F_1, F_5 \} \} \]

\[ CR(l_i) \rightarrow \{ 7, 4, 5, 6, 7 \} \]

\[ CR(T_A) = \max \{ CR(l_1), CR(l_2) \} = \max \{ 7, 4 \} = 7 \]
HEURISTIC SCHEDULING (8/12)
Flow Scheduling

Phase I
- select outgoing flow which has the **highest credit** among its candidate flows
- sends **back-to-back packets** on this flow with the packet concatenation (PAC) mechanism

Phase II
- priority-based scheduling policy
  - Traffic-control interframe space (TIFS)
    - length is set according to the transmitter’s credit.
Flow Scheduling

\[
TIFS = \begin{cases} 
0, & \text{if } \text{seq} = 1 \\
TIFS_{\text{min}}, & \text{if } TIFS = 0 \text{ and } \text{seq} > 1 \\
\min(TIFS \cdot \text{seq}, TIFS_{\text{max}}), & \text{otherwise}
\end{cases}
\]

- \text{seq} : one transmitter’s credit order among all the transmitters in its LCG.
- \text{seq} = 1 : the largest credit.
Example

\[\{S_m\} = \{S_1, S_2, S_3, S_4\} = \\{\{F_2\}, \{F_3\}, \{F_1, F_4\}, \{F_1, F_5\}\}\]

Case 1

\[U_i = \mu_i(1 + \lambda_i) \rightarrow \{2, 4, 5, 4, 5\}\]
\[\text{CR}(S_m) \rightarrow \{4, 5, 6, 7\}\]
\[\text{CR}(l_i) \rightarrow \{7, 4, 5, 6, 7\}\]
\[\text{CR}(T_A) = 7; \text{ CR}(T_B) = 7\]
\[A's \ TIFS = 0\]
Example

\[ \{S_m\} = \{S_1, S_2, S_3, S_4\} = \{\{F_2\}, \{F_3\}, \{F_1, F_4\}, \{F_1, F_5\}\} \]

Case 2

\[ U_i = \mu_i (1 + \lambda_i) \rightarrow \{2, 4, 10, 4, 5\} \]
\[ CR(S_m) \rightarrow \{4, 10, 6, 7\} \]
\[ CR(l_i) \rightarrow \{7, 4, 10, 6, 7\} \]
\[ CR(T_A) = 7; \quad CR(T_B) = 10 \]
\[ A's \ TIFS \neq 0 \]
Two-Transmitter Scenario

- 450 m: distance between a sender and a receiver
- 1800 m: the distance between the two transmitters larger than the average carrier sensing range.

By two-ray ground reflection model:

<table>
<thead>
<tr>
<th>Rates (Mbps)</th>
<th>11.0</th>
<th>5.5</th>
<th>2.0</th>
<th>1.0</th>
<th>Carrier sensing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rang (m)</td>
<td>399</td>
<td>531</td>
<td>669</td>
<td>796</td>
<td>1783</td>
</tr>
</tbody>
</table>
Two-Transmitter Scenario

QoS requirements

\( G_2 = G_3 = 1.5 \text{ Mb/s} \)
Random Flows in Grid Topology

14-flow example

450 m
Random Flows in Grid Topology

- 14-flow example

QoS requirements

\[ G_1 = G_2 = \ldots = G_6 = 1.0 \text{ Mb/s} \]
Random Flows in Grid Topology

- Random scenarios
- 10–16 flows are randomly generated
- Each transmitter has two-to-four single-hop flows to deliver
Random Topologies

- four transmitters are uniformly distributed in a 3 × 3-km square area
- Each transmitter has three candidate receivers which are uniformly distributed in a round area with a radius of $D_{\text{max}}$
Random Topologies
CONCLUSIONS

- The key contributions of this paper
  - An interference-dependent multiuser diversity model is given for the ad hoc networks while considering the QoS requirement of each flow.
  - An optimal criterion is presented to find the globally optimal set of simultaneously transmitting flows.
  - An IEEE 802.11-based QoS-aware distributed cooperative and opportunistic scheduling (COS) is designed, which obtains higher network throughput and better QoS support than the existing schemes with limited local information.