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

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OUTLINE

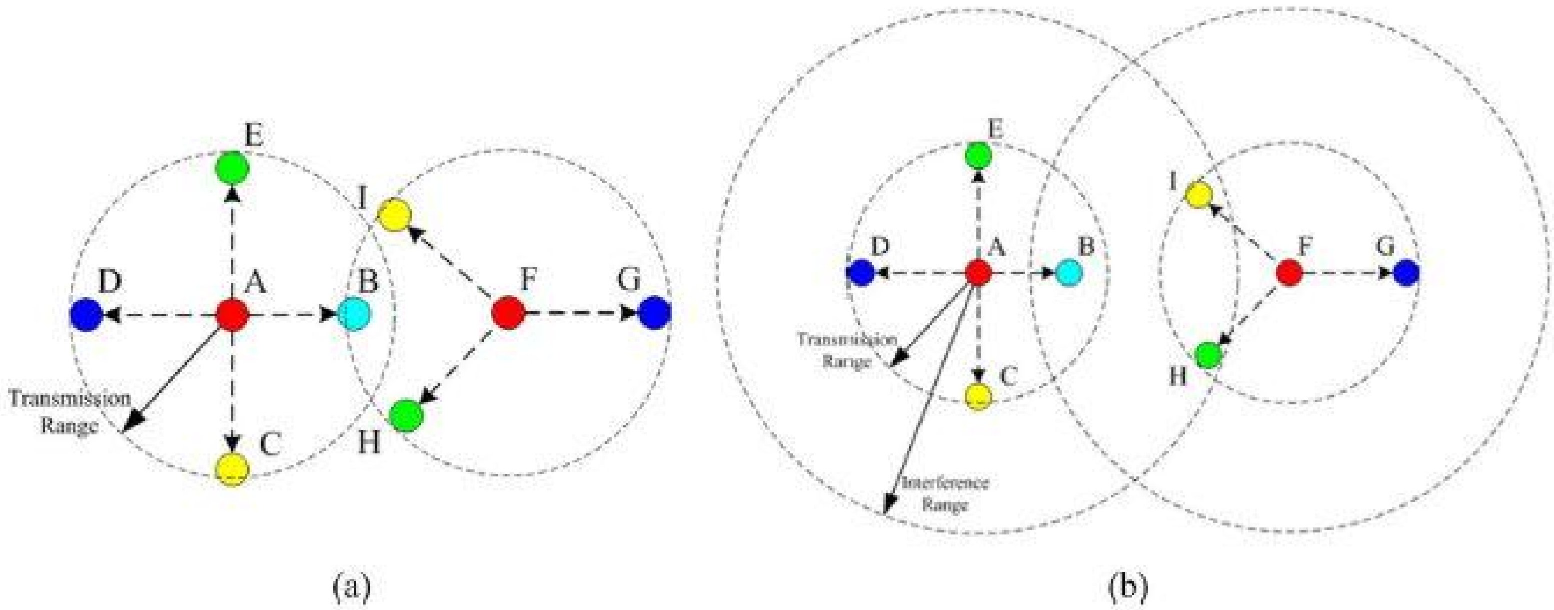
- INTRODUCTION
- PROBLEM FORMULATION
- OPTIMAL CRITERIA OF SCHEDULING
- HEURISTIC SCHEDULING
- SIMULATION RESULT
- CONCLUSIONs

INTRODUCTION (1/3)

- 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)

INTRODUCTION (2/3)

- Two examples with two transmitters



INTRODUCTION (3/3)

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

PROBLEM FORMULATION

- The opportunistic scheduling:

$$\max_{Q} \quad \sum_{i \in \mathcal{N}} E\left\{ f_i\left(\mu_i(t)\right) I_{i \in Q(t)} \right\}$$

$$\text{s.t.} \quad E\left\{ g_i\left(\mu_i(t)\right) I_{i \in Q(t)} \right\} \geq G_i \quad \forall i \in \mathcal{N}$$

$$c(i, j, t) = 0 \quad \forall i, \quad j \in Q(t), \quad i \neq j$$

  - $\mu_i(t)$: ith flow's feasible data rate, in timeslot t
  - $f_i(\mu_i(t))$: utility function
  - 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 (1/2)

- The flow set selected by optimal scheduling should be a **MIS** (Maximal Independent Subset)
- The optimal solution of the opportunistic scheduling:

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

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

  - λ_i's ：the Karush–Kuhn–Tucker (KKT) multipliers (ith flow's QoS factor)

OPTIMAL CRITERIA OF SCHEDULING (2/2)

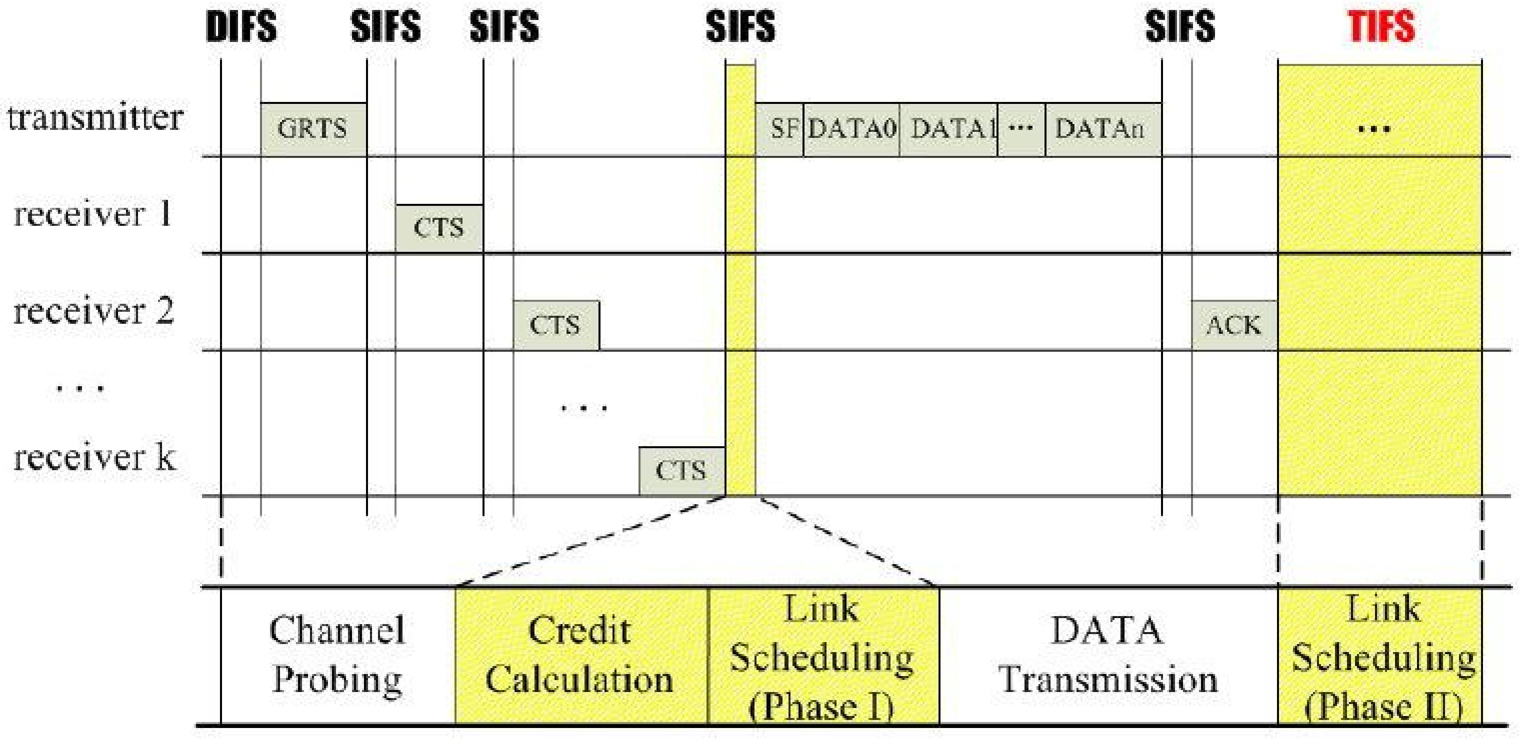
- Focus on the **minimum bandwidth constraints** and the **network throughput maximization**
  - $g_i(\mu_i) = f_i(\mu_i) = \mu_i$
- Optimal criteria

$$Q^*(t) = S_{m^*}(t),\, m^* = \arg\max_{m} \left\{ \sum_{i \in S_m} \mu_i (1 + \lambda_i) \right\}$$

HEURISTIC SCHEDULING (1/12)

- 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 (2/12)

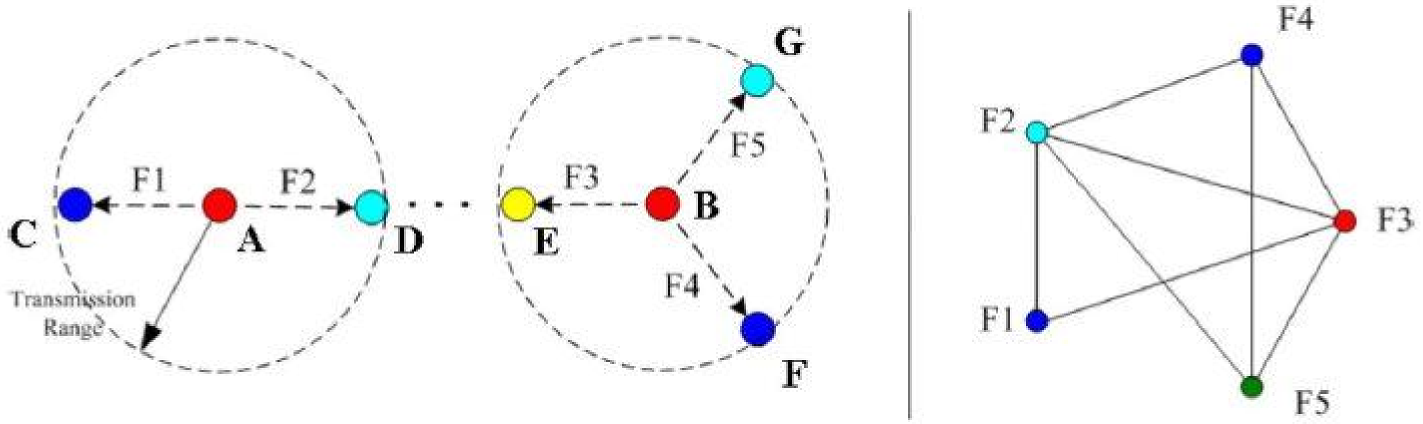


HEURISTIC SCHEDULING (3/12)

- 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.

HEURISTIC SCHEDULING (4/12)

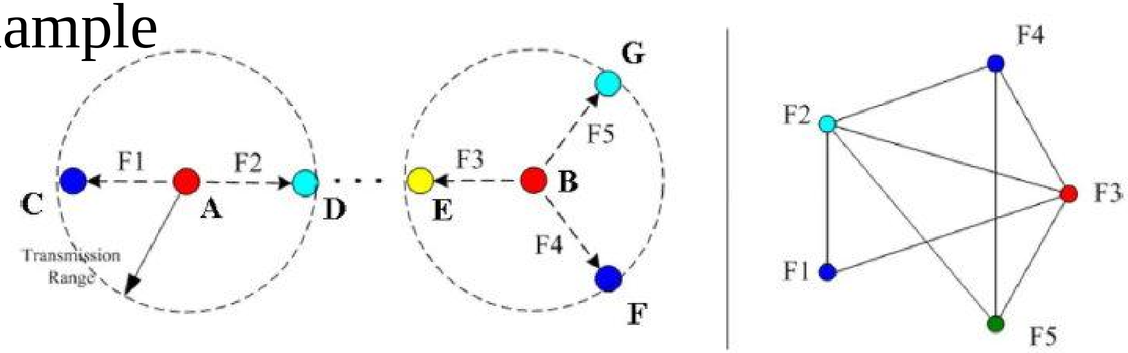
- Credit Calculation
  - CR(X)：credit function which returns the credit of entity X
  - Two-Transmitter Scenario



- $\{S_m\} = \{S_1, S_2, S_3, S_4\} = \{\{F_2\}, \{F_3\}, \{F_1, F_4\}, \{F_1, F_5\}\}$

HEURISTIC SCHEDULING (5/12)

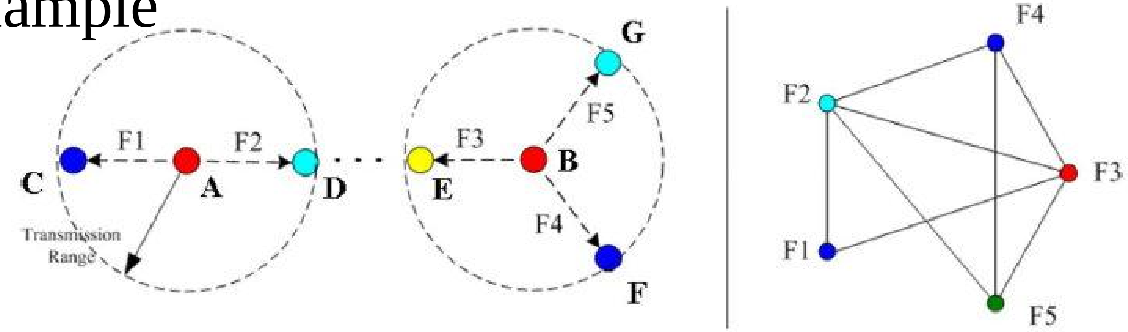
- Credit Calculation
  - A MIS's credit
    - $\mathrm{CR}(S_m) = \sum_{i \in S_m} \mu_i (1 + \lambda_i)$
  - Example



- $\{S_m\} = \{S_1, S_2, S_3, S_4\} = \{\{F_2\}, \{F_3\}, \{F_1, F_4\}, \{F_1, F_5\}\}$
- $U_i = \mu_i(1+ \lambda_i) \rightarrow \{2, 4, 5, 4, 5\}$
- $CR(S_3) = U_1 + U_4 = 2 + 4 = 6$
- $CR(S_m) \rightarrow \{4, 5, 6, 7\}$

HEURISTIC SCHEDULING (6/12)

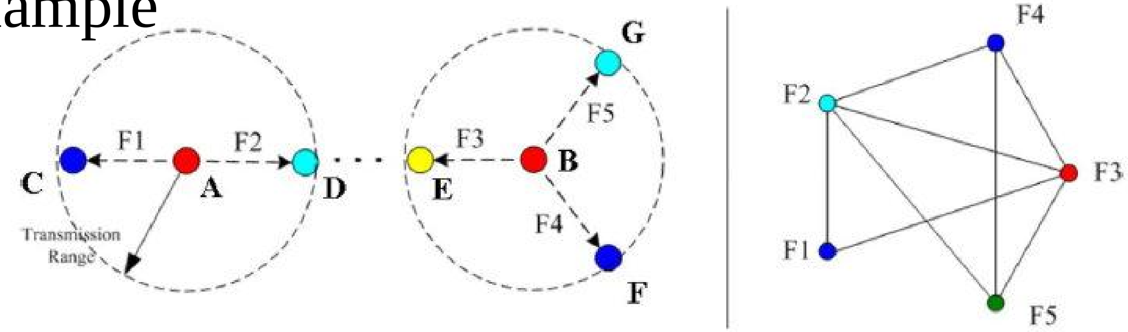
- Credit Calculation
  - A flow's credit
    - $CR(l_i) = \max_m \{CR(S_m) \mid i \in S_m\}$
  - Example



- $\{S_m\} = \{S_1, S_2, S_3, S_4\} = \{\{F_2\}, \{F_3\}, \{F_1, F_4\}, \{F_1, F_5\}\}$
    - $CR(S_m) \rightarrow \{4, 5, 6, 7\}$
    - $CR(l_1) = \max \{CR(S_3), CR(S_4)\} = \max \{6, 7\} = 7$
    - $CR(l_i) \rightarrow \{7, 4, 5, 6, 7\}$

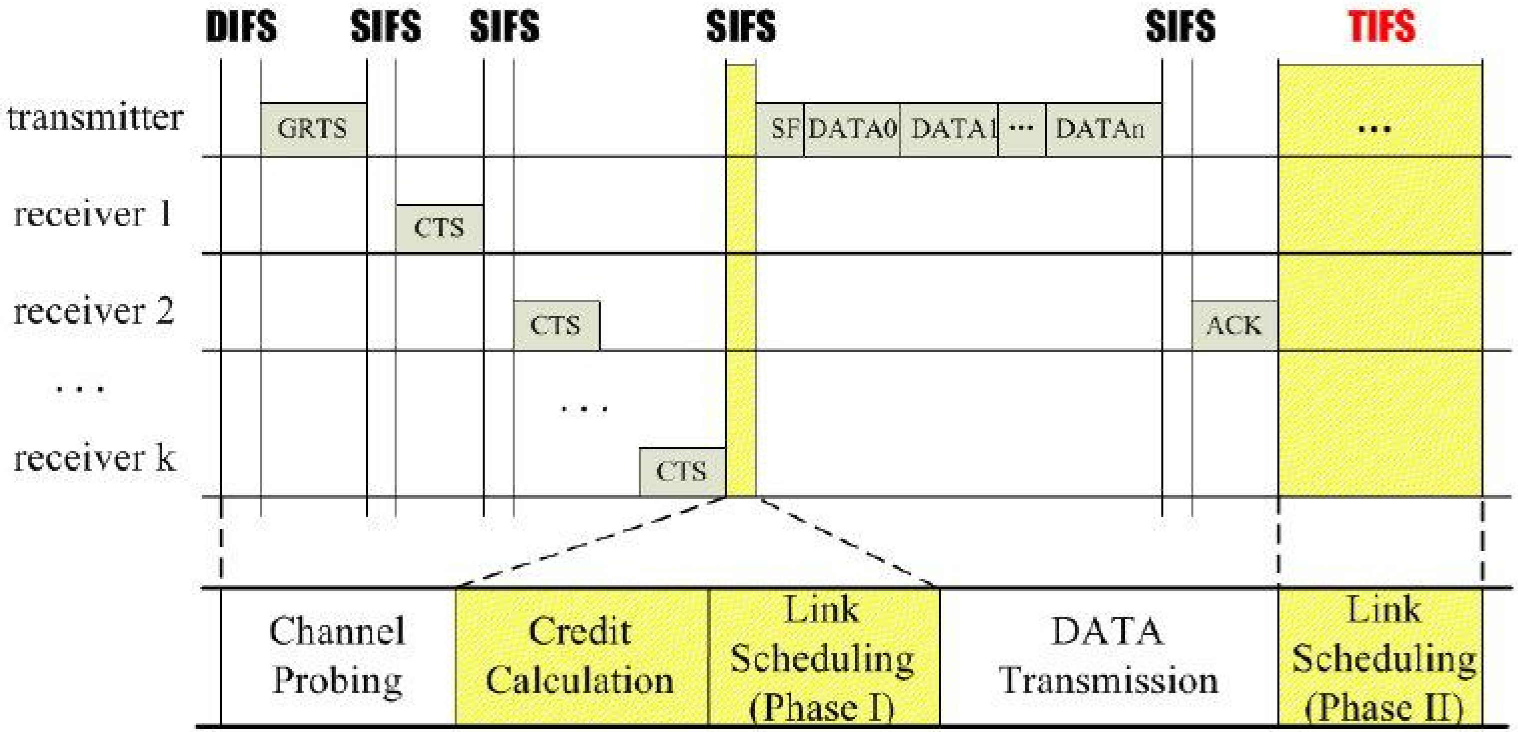
HEURISTIC SCHEDULING (7/12)

- 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)



HEURISTIC SCHEDULING (9/12)

- 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.

HEURISTIC SCHEDULING (10/12)

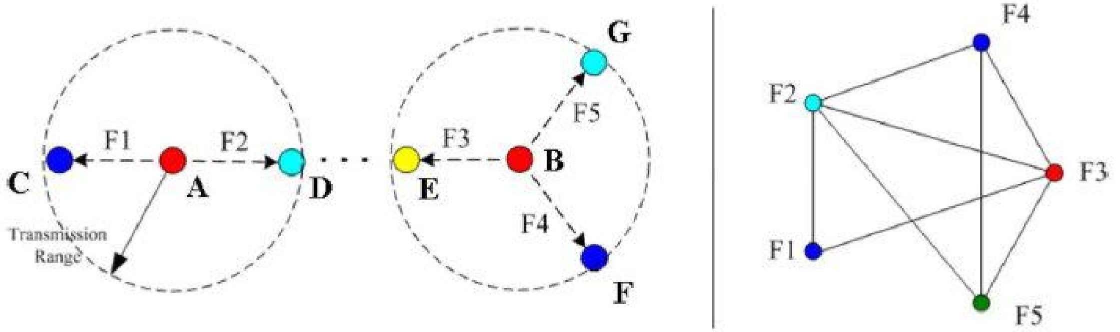
- Flow Scheduling

$$\text{TIFS} = \begin{cases} 0, & \text{if seq} = 1 \\ \text{TIFS}_{\min}, & \text{if TIFS} = 0 \text{ and seq} > 1 \\ \min(\text{TIFS} \cdot \text{seq}, \\ \qquad \text{TIFS}_{\max}), & \text{otherwise} \end{cases}$$

  - seq：one **transmitter's credit order** among all the transmitters in its **LCG**.
  - seq = 1：the largest credit.

HEURISTIC SCHEDULING (11/12)

- Example

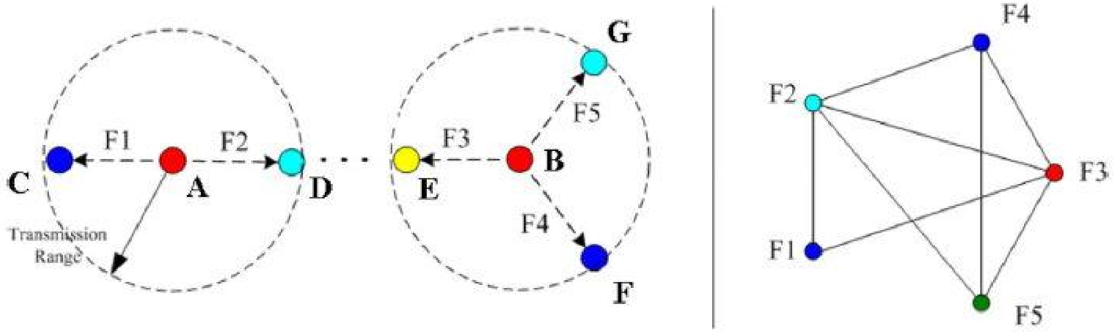


  - $\{S_m\} = \{S_1, S_2, S_3, S_4\} = \{\{F_2\}, \{F_3\}, \{F_1, F_4\}, \{F_1, F_5\}\}$

- Case 1
  - $U_i = \mu_i(1+ \lambda_i) \rightarrow \{2, 4, 5, 4, 5\}$
  - $CR(S_m) \rightarrow \{4, 5, 6, 7\}$
  - $CR(l_i) \rightarrow \{7, 4, 5, 6, 7\}$
  - **$CR(T_A) = 7$ ； $CR(T_B) = 7$**
  - **A's TIFS = 0**

HEURISTIC SCHEDULING (12/12)

- 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
  - $U_i = \mu_i(1+\lambda_i) \rightarrow \{2, 4, 10, 4, 5\}$
  - $CR(S_m) \rightarrow \{4, 10, 6, 7\}$
  - $CR(l_i) \rightarrow \{7, 4, 10, 6, 7\}$
  - **$CR(T_A) = 7$； $CR(T_B) = 10$**
  - **A's TIFS != 0**

SIMULATION RESULT (1/7)

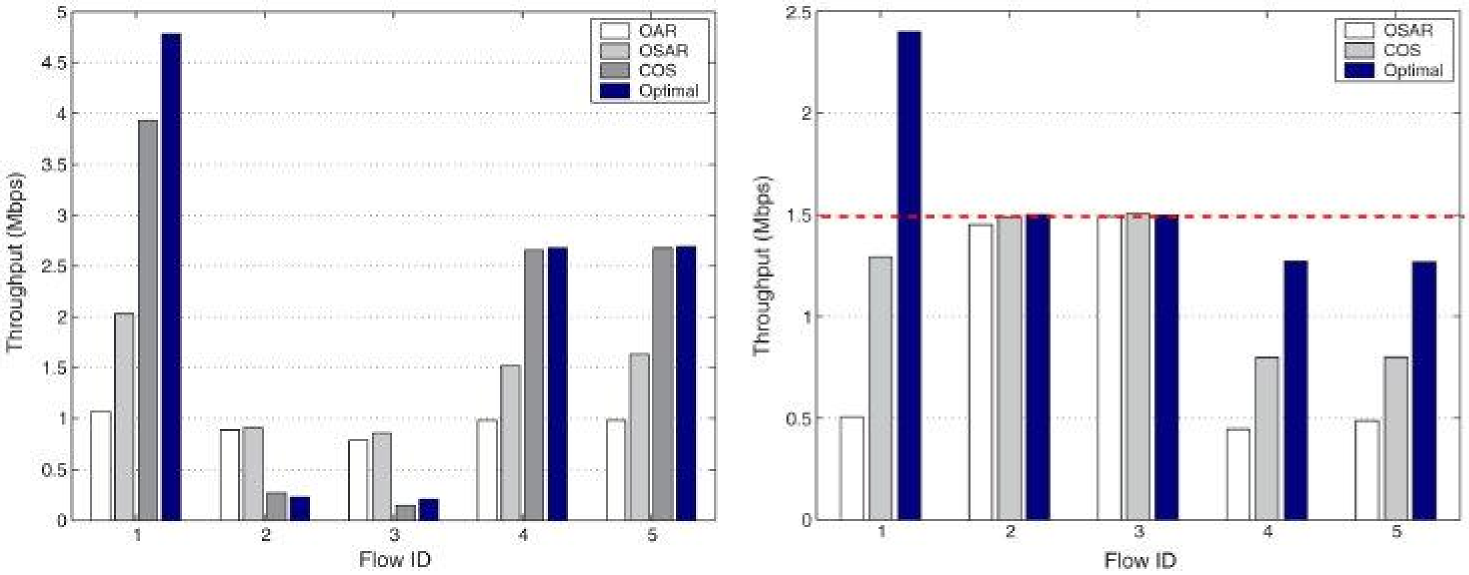
- Two-Transmitter Scenario
  - 450 m：distance between a sender and a receiver
  - 1800 m：the distance between the two transmitters
    - larger than the average carrier sensing range.

By two-ray ground reflection model:

Rates (Mbps)	11.0	5.5	2.0	1.0	Carrier sensing
Rang (m)	399	531	669	796	**1783**

SIMULATION RESULT (2/7)

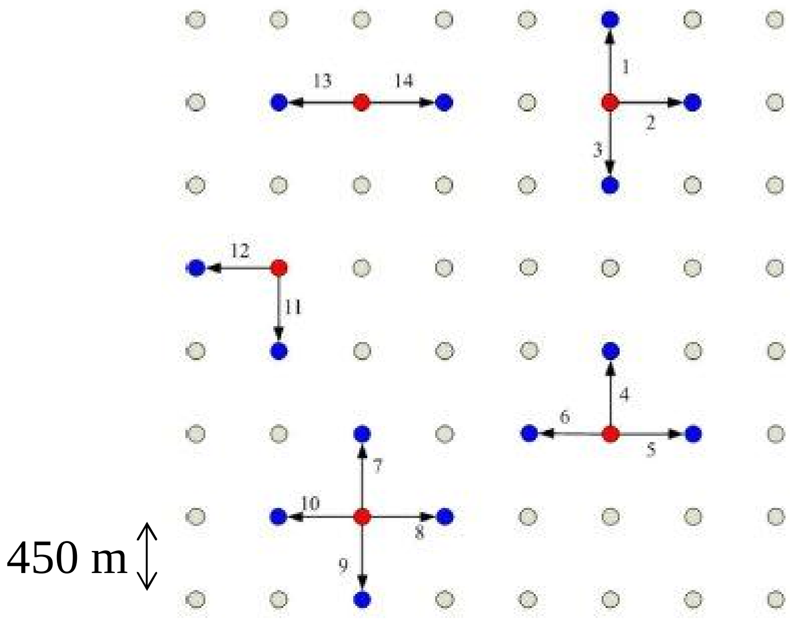
- Two-Transmitter Scenario



QoS requirements
$G_2 = G_3 = 1.5$ Mb/s

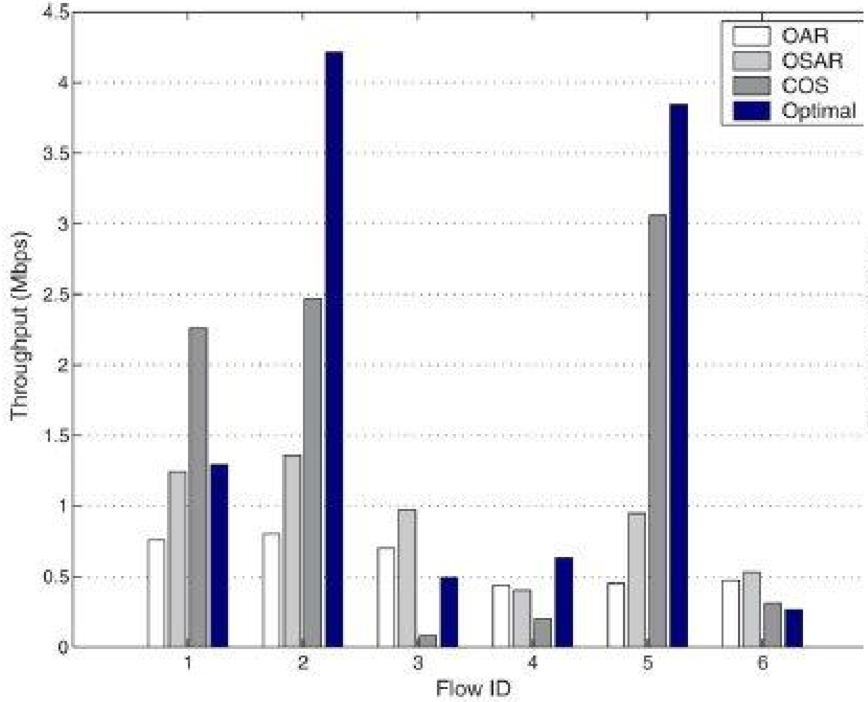
SIMULATION RESULT (3/7)

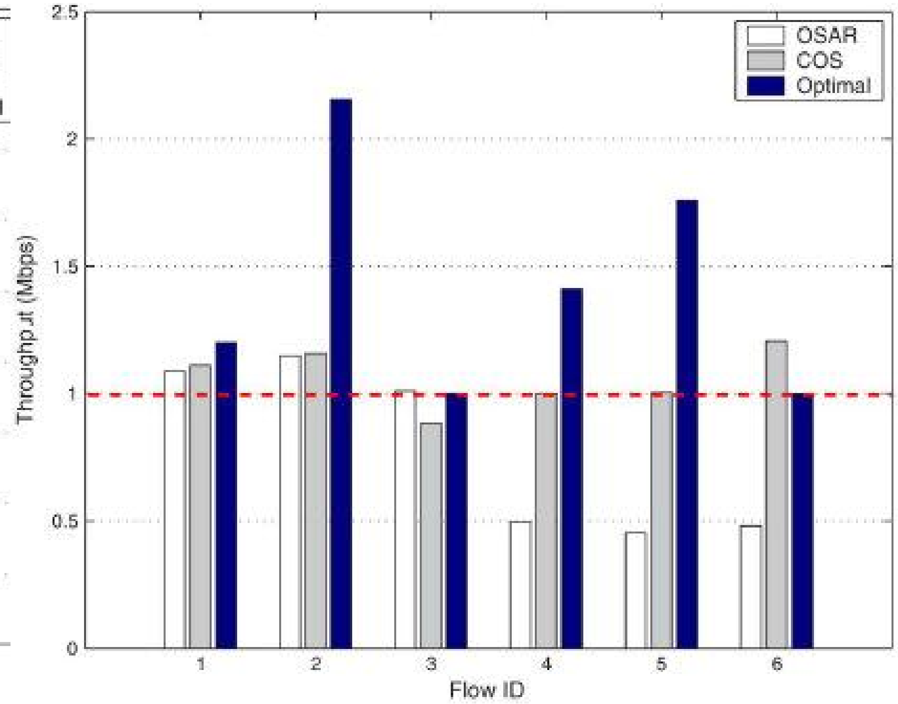
- Random Flows in Grid Topology
  - 14-flow example



SIMULATION RESULT (4/7)

- Random Flows in Grid Topology
  - 14-flow example



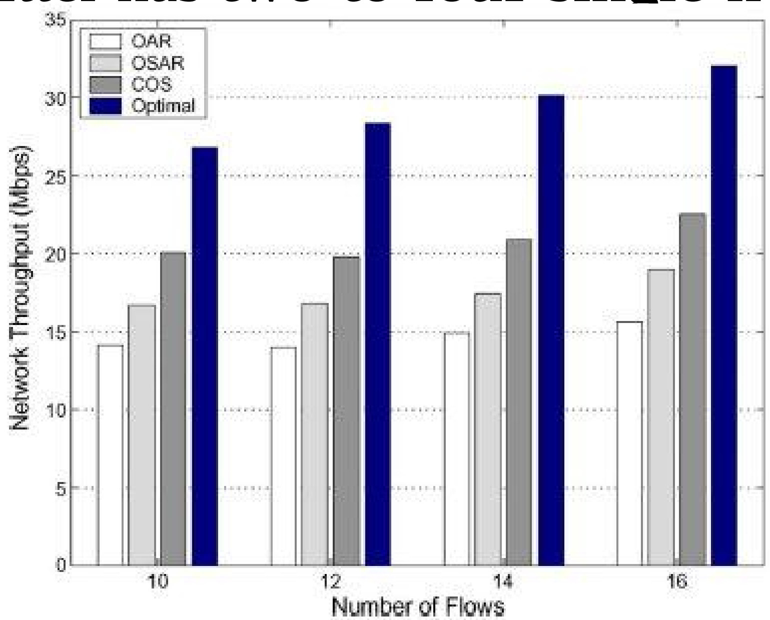


QoS requirements

$G_1 = G_2 = \ldots = G_6 = 1.0$ Mb/s

SIMULATION RESULT (5/7)

- Random Flows in Grid Topology
  - random scenarios
    - 10–16 flows are randomly generated
    - each transmitter has **two-to-four single-hop** flows to deliver

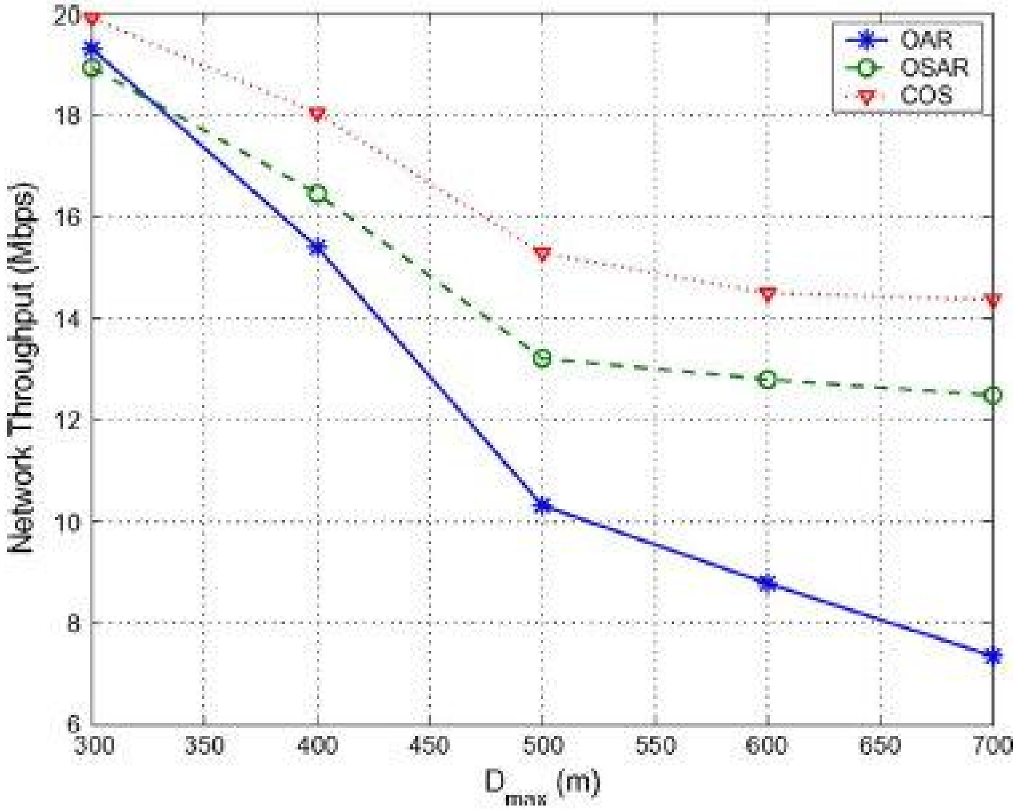


SIMULATION RESULT (6/7)

- 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_{max}**

SIMULATION RESULT (7/7)

- 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.