Femto-Cloud Formation: A Coalition Game-Theoretic Approach

S. M. Shahrear Tanzil, Omid Namvar Gharehshiran, and Vikram Krishnamurthy

Department of Electrical and Computer Engineering
University of British Columbia, Vancouver, Canada

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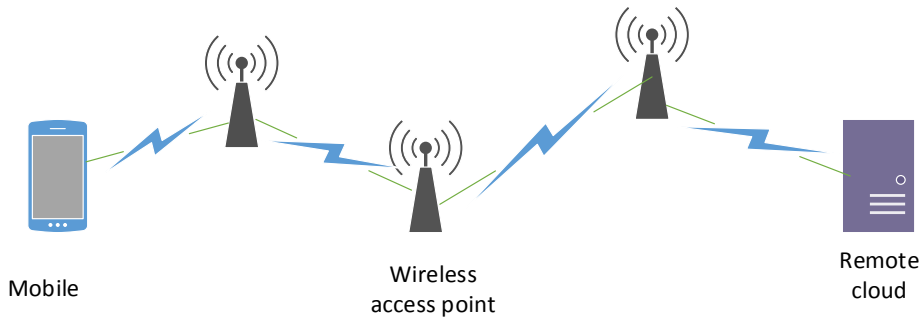
Outline

Mobile cloud computing

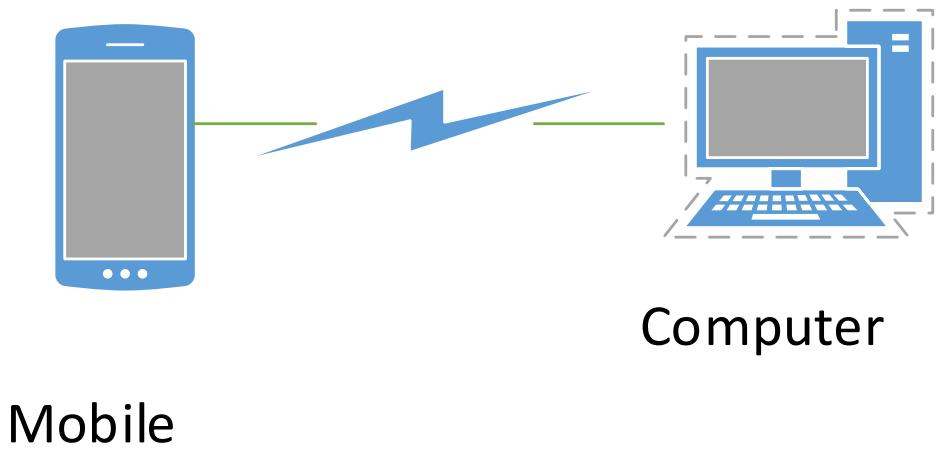
- Mobile cloud computing (MCC): Offloading computation and storage to the remote cloud over the wireless/wired networks
  - Major bottlenecks in MCC
    - ★ Energy
    - ★ Latency



Mobile cloud computing

Cloudlet

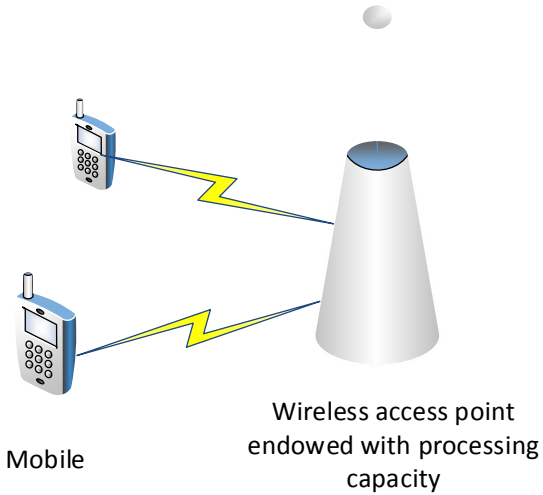
- *Cloudlet*: A trusted local cloud, comprised of multi-core computers, connected to the Internet, and available for use within the proximity of mobile users
  - Mobile devices use Wi-Fi network to offload the computation tasks to the *Cloudlet*



Cloudlet

Small cell cloud

- Small cell access points are augmented with computational power
- The advantage is that small cells, in contrast to Wi-Fi, work under the same communication standard as the LTE cellular network

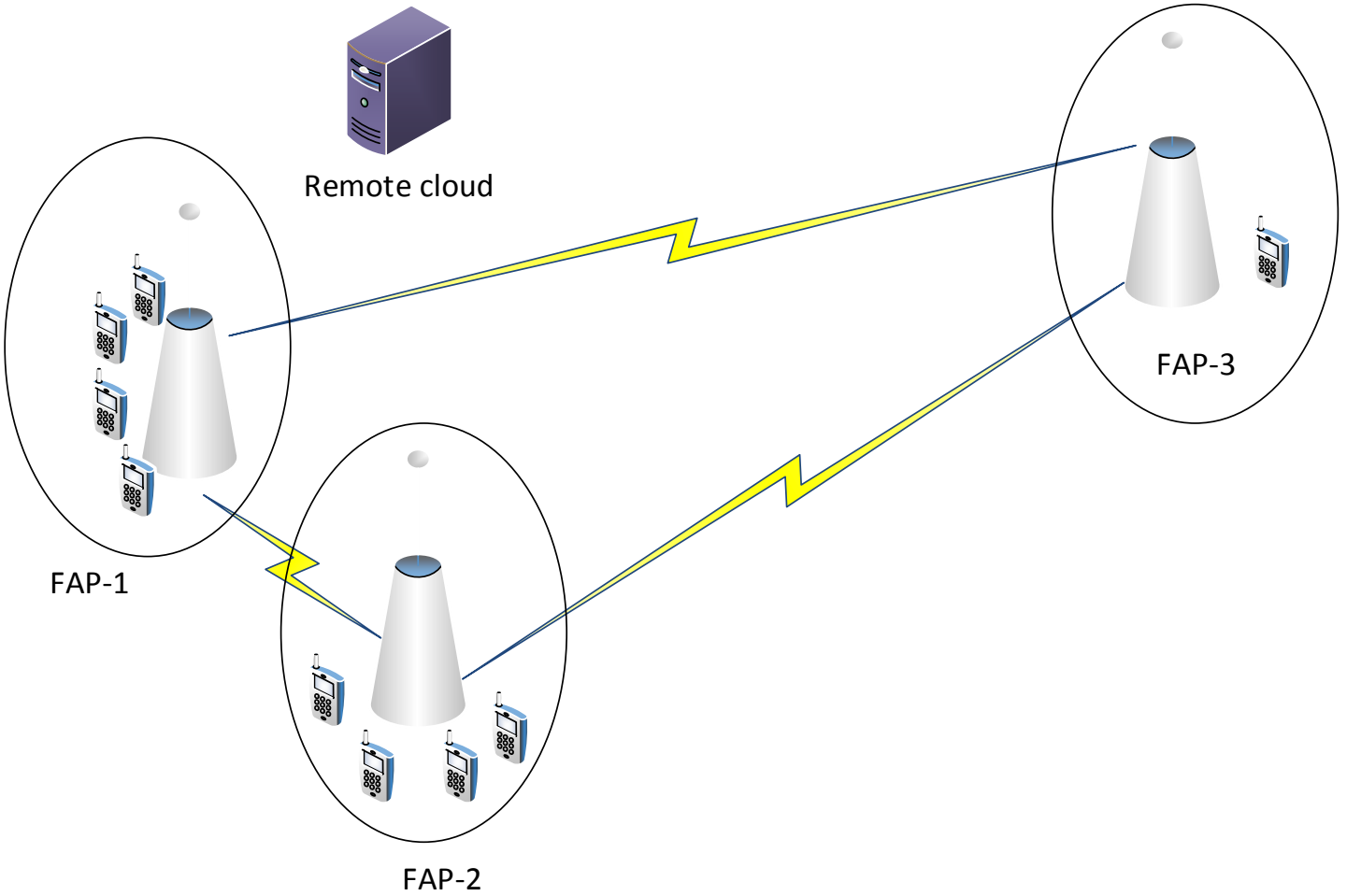


Small cell cloud

Main Idea

- FAPs are willing to share their computational resources with the neighbouring FAPs in exchange for monetary incentives
- Question: How should FAPs form local femto-clouds where groups of FAPs establish collaborative coalitions to perform jointly the computational tasks within the coalition so that both the end-user and FAP owners experiences are improved?

Example Scenario-1



Our Contributions

- The femto-cloud formation problem is formulated:
  - An incentive based coalition formation cooperative game with transferable utility
  - Core of the game provides the solution to the femto-cloud formation problem

Femto-Clouds Utility

- In our formulation, we take into account:
  - The profile of request arrivals in individual FAPs
  - The data transfer delay among FAPs
  - Computational capacity of FAPs
  - The data transfer delay and computational cost in remote cloud
- Propose incentive mechanism to FAP owners so as to motivate to share their resources.

Femto-Clouds Utility

$$U(\mathcal{C}) = U^r(\mathcal{C}) - U^c_r(\mathcal{C}) - U^c_{o,r}(\mathcal{C}) - U^c_{o,m}(\mathcal{C}) \quad (1)$$

- $U(\mathcal{C})$ denotes the utility function of coalition $\mathcal{C}$ i.e., total revenue earned by the coalition
  - $U^r(\mathcal{C})$ denotes the revenue earned by the coalition $\mathcal{C}$
  - $U^c_r(\mathcal{C})$ denotes the remote cloud processing cost
  - $U^c_{o,r}(\mathcal{C})$ represents the remote cloud offloading delay cost
  - $U^c_{o,m}(\mathcal{C})$ represents the multicast offloading delay in the coalition $\mathcal{C}$

Femto-Cloud Formation

- $\mathcal{K}$ represents the set of all FAPs, and $2^{\mathcal{K}}$ denotes its power set
- $\mathcal{S}$ represents the femto-cloud structure
- $\mathcal{B}$ denotes the set of all possible coalition structures
- $\mathcal{C}$ denotes an individual coalition in the coalition structure $\mathcal{B}$
- Δ (\$) is the smallest payoff unit
- $\mathcal{P}$ denotes FAPs' demand set
- K total number of FAPs

Femto-Cloud Formation

- Femto-cloud formation problem:

$$\max_{\mathcal{S}\in\mathcal{B}} \sum_{\mathcal{C}\in\mathcal{B}} U(\mathcal{C})$$

$$\text{s.t.} \quad \sum_{k\in\mathcal{C}} r_k = \lfloor U(\mathcal{C}) \rfloor_\Delta, \qquad \forall \mathcal{C} \in \mathcal{B}$$

$$\sum_{k\in\mathcal{C}} r_k \geq U(\mathcal{C}'), \qquad \forall \mathcal{C}' \in 2^{\mathcal{K}} - \emptyset, \mathcal{C}' \notin \mathcal{B}$$

$$r_k \in \mathcal{P}, r_k \geq U(\{k\}), \quad \forall k \in \mathcal{K}$$

- $\mathbf{r} = (r_1, \ldots, r_K)$ denotes the revenue allocation vector i.e., the share of each FAP from the revenue obtained by the femto-clouds

$$\mathbf{r} \cdot \mathbf{1}_K = \max_{\mathcal{S} \in \mathcal{B}} \sum_{\mathcal{C} \in \mathcal{S}} \lfloor U(\mathcal{C}) \rfloor_\Delta, \quad r^k \in \mathcal{P}_k$$

$$\sum_{k \in \mathcal{C}} r^k \geq \lfloor U(\mathcal{C}) \rfloor_\Delta, \quad \forall \mathcal{C} \subseteq \mathcal{K}, \mathcal{C} \neq \emptyset.$$

- Dynamic coalition formation algorithm is utilized with modified core for femto-cloud formation

Algorithm-1

Initialization. Set $0 < \varepsilon, \rho < 1$, and initialize $\omega^0 = (\mathcal{S}^0, \mathbf{r}^0)$, where

$$\mathcal{S}^0 = \{\{1\}, \ldots, \{K\}\}, \text{ and } \mathbf{r}^0 = \left(\hat{r}_1, \ldots, \hat{r}_K\right)$$

Here, $\hat{r}_k = U(\{k\})$ is the reservation incentive for FAP k.

Step 1. Find Blocking coalitions:
Let $\mathcal{A}^n = \emptyset$. For all $\mathcal{C} \in 2^{\mathcal{K}} - \emptyset$,

$$\text{if } \sum_{l \in \mathcal{C}} r_l^n \leq \lfloor U(\mathcal{C}) \rfloor_\Delta, \text{ then } \mathcal{A}^n \leftarrow \mathcal{A}^n \cup \mathcal{C}.$$

Step 2. For each $k = \{1, \ldots, K\}$, do:

Step 2.1. With probability ρ, stay in the same coalition, set $r_k^{n+1} = r_k^n$, and go to Step 2.5. With the remaining probability $1 - \rho$, continue with Step 2.2.

Step 2.2. Compute

$$\tilde{\mathcal{C}}_k^{n+1} = \underset{\mathcal{C} \in \mathcal{S}^n \cup \emptyset}{\operatorname{argmax}} \left(\lfloor U(\mathcal{C} \cup \{k\}) \rfloor_\Delta - \sum_{l \in \mathcal{C} - \{k\}} r_l^n \right) \tag{2}$$

$$\tilde{\mathbf{r}}_k^{n+1} = \lfloor U(\tilde{\mathcal{C}}_k^{n+1} \cup \{k\}) \rfloor_\Delta - \sum_{l \in \tilde{\mathcal{C}}_k^{n+1} - \{k\}} r_l^n \tag{3}$$

Step 2.3. If $k \in \mathcal{A}^n$, with probability ε, go to Step 2.4. With the remaining probability $1 - \varepsilon$, sample uniformly from the set $\mathcal{S}^n \cup \emptyset$, denote it by $\tilde{\mathcal{C}}_k^{n+1}$, and set $r_k^{n+1} = \tilde{r}_k^{n+1}$, where $\tilde{r}_k^{n+1}$ is computed according to (3).

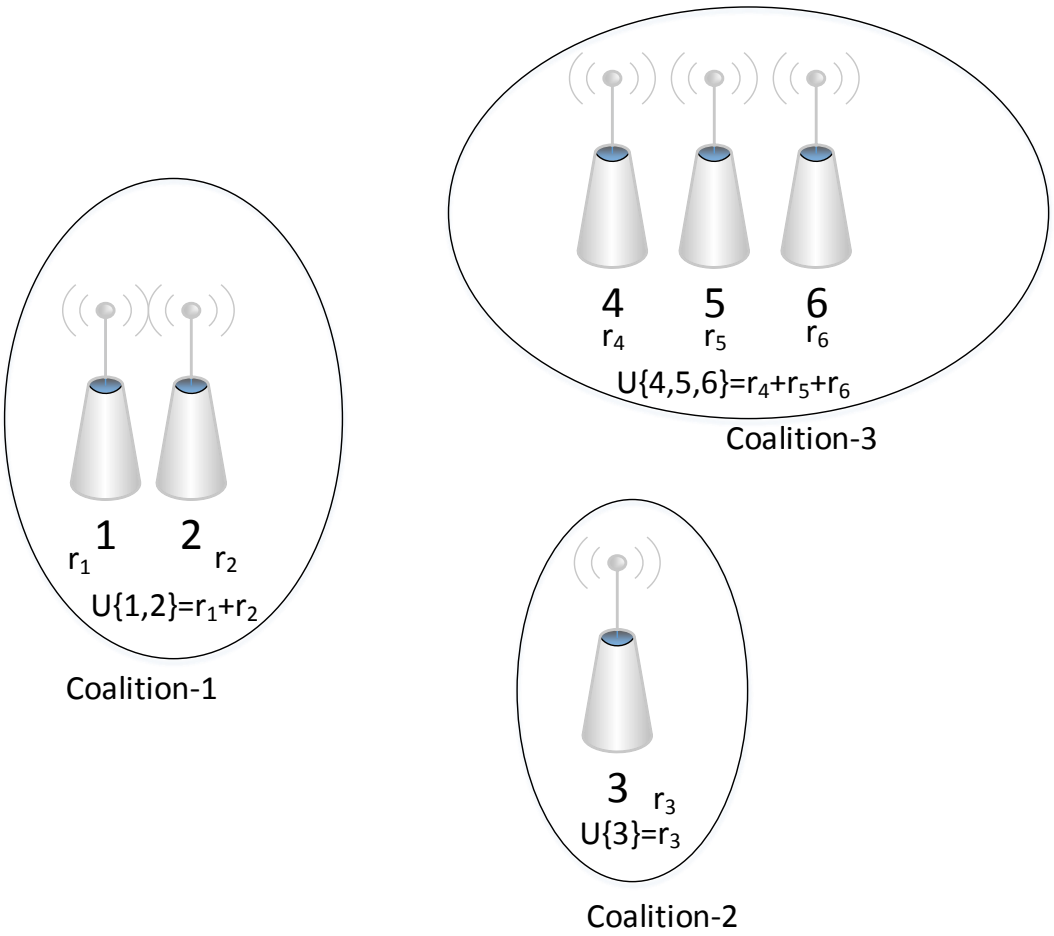
Go to Step 2.5.

Step 2.4. Set $r_k^{n+1} = \tilde{r}_k^{n+1}$ and, if non-singleton, randomize among $\tilde{\mathcal{C}}_k^{n+1}$ uniformly.

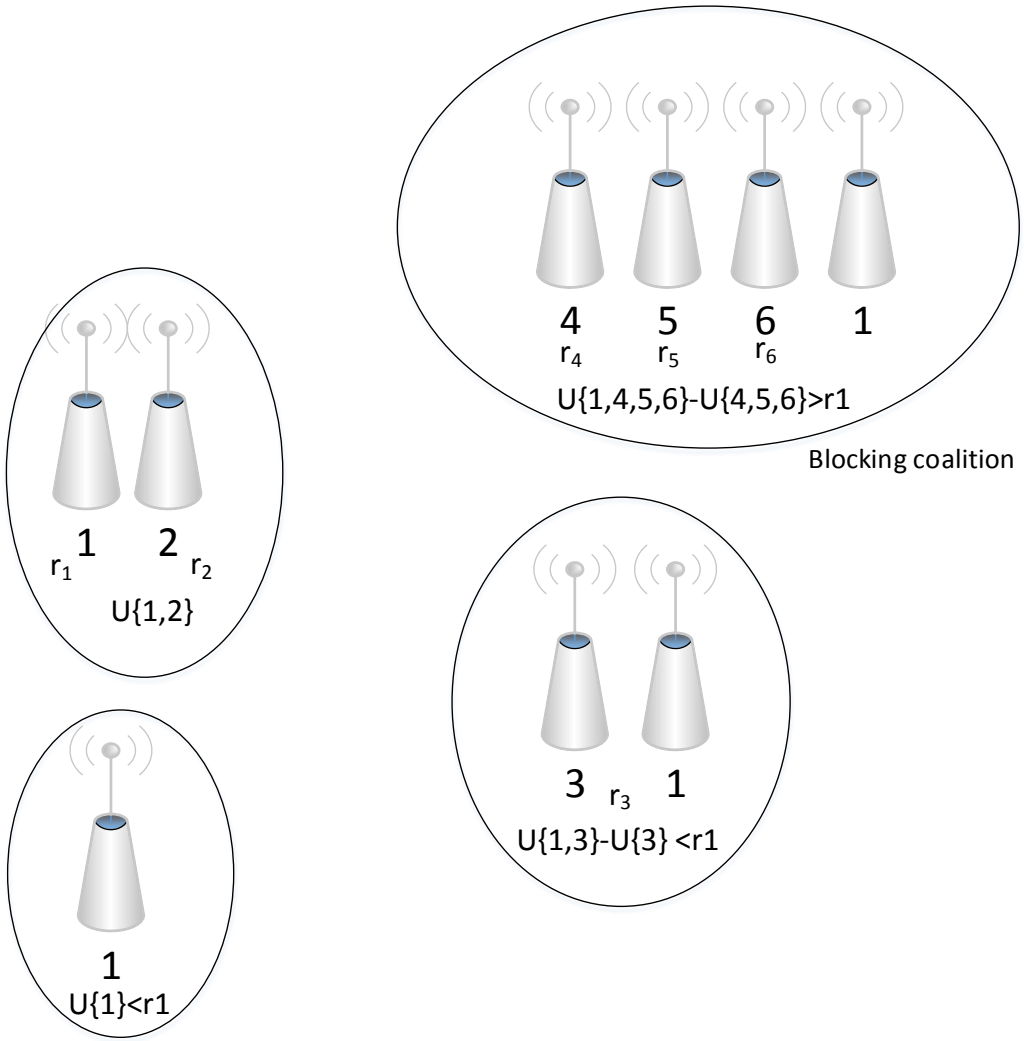
Step 2.5. If $k \neq K$, continue with the next FAP.

Step 3. Form $\omega^{n+1} = (\mathcal{S}^{n+1}, \mathbf{r}^{n+1})$. Set $n \leftarrow n+1$ and go to Step 1.

Example-1


4
r4
5
r5
6
r6
U{4,5,6}=r4+r5+r6
Coalition-3
1
r1
2
r2
U{1,2}=r1+r2
Coalition-1
3
r3
U{3}=r3
Coalition-2

Example-2


4
r4
5
r5
6
r6
1
U{1,4,5,6}-U{4,5,6}>r1
Blocking coalition
1
r1
2
r2
U{1,2}
3
r3
1
U{1,3}-U{3} <r1
1
U{1}<r1

Simulation set-up

- Object recognition from images
- MAUI offloading mechanism
- LTE LENA module in NS3

Comparison

- Algorithm-1: Our proposed femto-cloud formation scheme
- *Grand Femto-cloud*: All the FAPs form one large collaborative coalition
- Heuristic scheme-1: Based on the relative distances
- Heuristic scheme-2: Based on the computational capacities and mean demands

Example-1: Enterprise environment

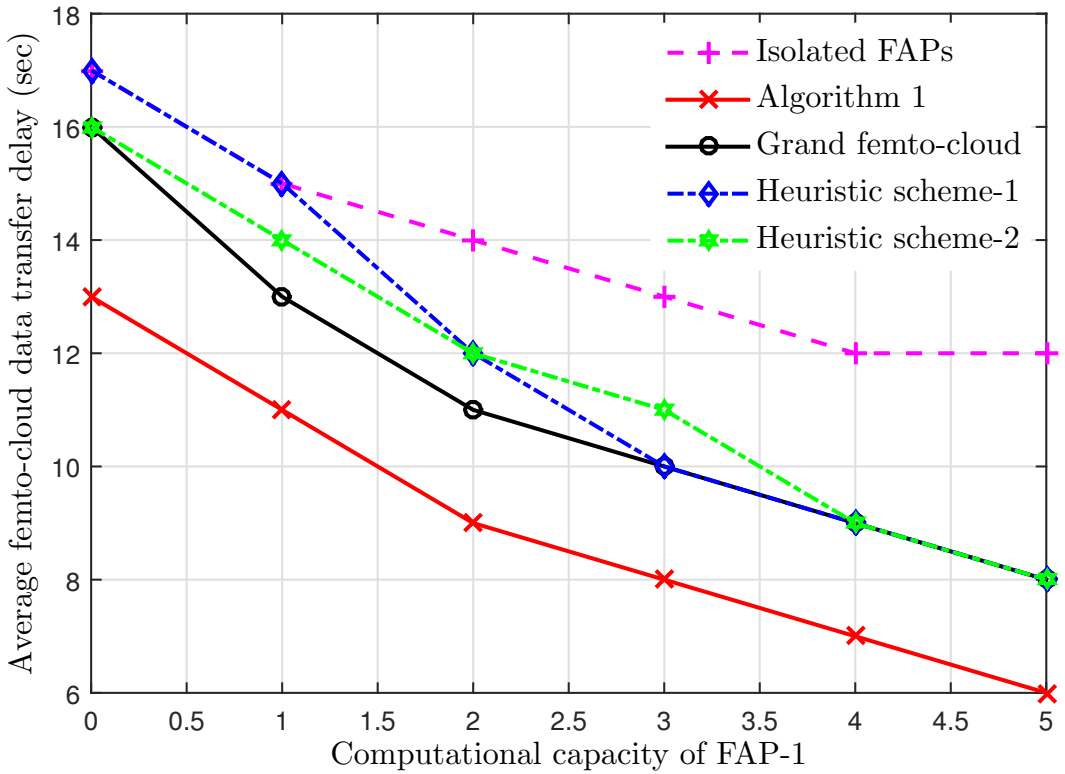


Figure 1: Computational capacity of FAP-1 vs. average data transfer delay in the femto-clouds

Example-2: Residential environment

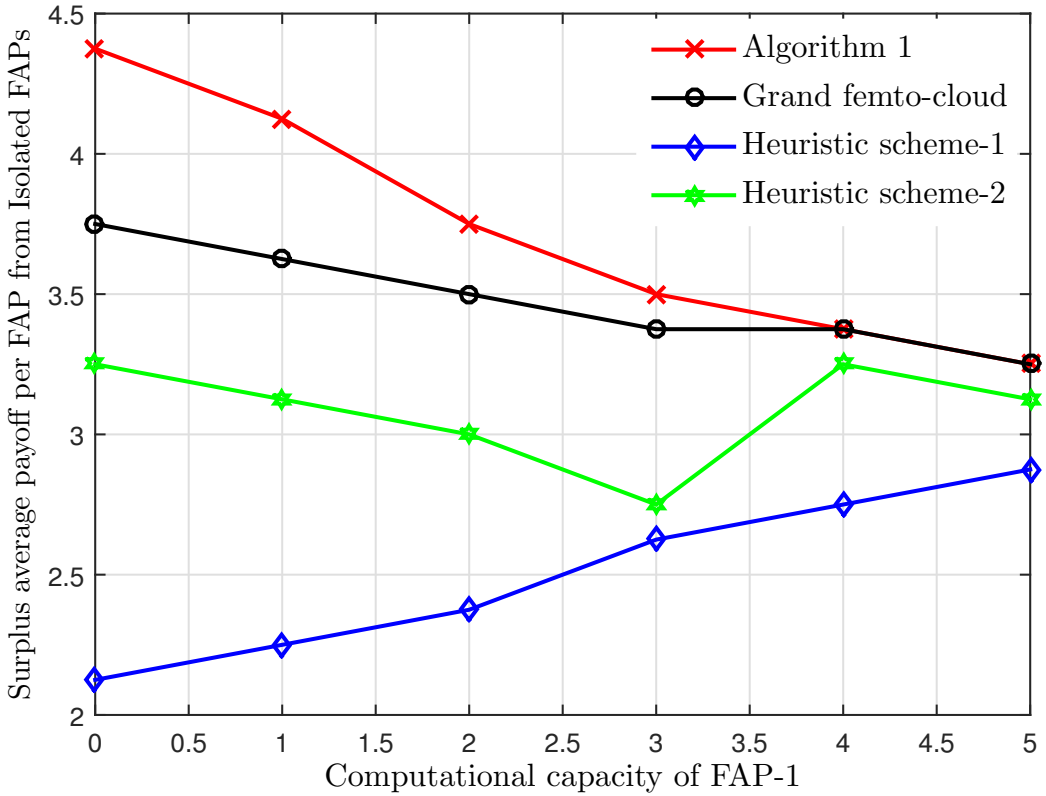


Figure 2: Computational capacity of FAP-1 vs. surplus average incentive per FAP from Isolated FAPs

Conclusion

- An incentive-based femto-cloud formation scheme was proposed
- The problem was formulated as a coalition game where coalition structures and payoff allocations in the core of the game correspond to the solution to the femto-cloud formation problem
- Numerical examples implemented on the LTE protocol stack in NS3:
  - Illustrate superior performance of the proposed scheme in terms of both handing latency and incentives provided to the FAP owners over alternative femto-cloud formation schemes
  - In most cases, grand coalition is not the optimal structure


Thank
You!!!
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Question?