Data Offloading in Mobile Cloud Computing: A Markov Decision Process Approach

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Overview

Research Background

- As mobile devices (e.g., smartphones and tablets) are gaining enormous popularity, more and more mobile services are emerging and consuming large amounts of cellular network resources. The growing speed of mobile traffic will push the current cellular network to the limit.
- The tension between data-intensive services and resource-constrained cellular network poses a significant challenge for mobile network operator (MNO).
- Mobile data offloading is considered as a promising approach to address such a challenge, which can offload mobile data (originally targeted to cellular network) to alternative wireless networks such as WiFi and device-to-device (D2D) networks.

Problem Statement

- We conclude that most existing contributions are based on WiFi offloading or opportunistic networks, without considering the combination of different mobile networks.
- In this paper, we consider three offloading modes: remote cloud service mode, connected ad hoc cloudlet service mode, and opportunistic ad hoc cloudlet service mode. Thus, MS can receive data from cellular, WiFi and D2D networks.
- Our objective is to minimize the overall cost for data delivery while satisfying delay requirements for different data types.

Method

In this paper, we propose a Finite Horizon Markov Decision Process (FHMDP) to formulate this problem, with the aim to minimize communication costs and satisfy delay constraints.

MDP

Markov decision process is a useful model for sequential decision making, where MNO needs to take a sequence of actions (wireless network selection).

FHMDP

FHMDP is a Markov decision process with a finite number of decision epochs. Since every data delivery task should be finished before a given deadline, FHMDP will plan data offloading decisions at each decision epoch.

System model: single MS case

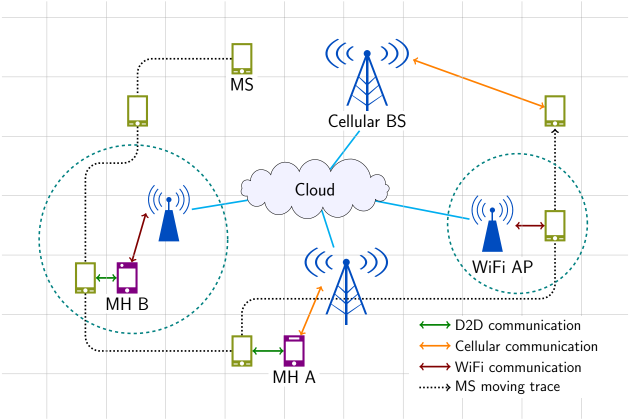

Figure 1: An illustration of data offloading in Mobile Cloud Computing

System State

$$s = (l, u, k, \mathcal{H}) \tag{1}$$

Notations

- l denotes the location of MS.
- u is the data type.
- k is the size of data to be transmitted.
- $\mathcal{H}$ denotes the locations of mobile helpers.

System Actions

$$a \in \mathcal{A} = \{1, 2, 3, 4\} \tag{2}$$

$$\mathcal{A}(l, u) = \begin{cases} \{1, 2\}, & l \in \mathcal{L}_d^1,\ u \in \mathcal{U} \\ \{1, 2, 3\}, & l \in \mathcal{L}_d^2,\ u \in \mathcal{U} \\ \{1, 2, 4\}, & l \in \mathcal{L}_d^3,\ u \in \mathcal{U}^0 \\ \{1, 2, 3, 4\}, & l \in \mathcal{L}_d^4,\ u \in \mathcal{U}^0 \end{cases} \tag{3}$$

Notations

- $a = 1, 2, 3, 4$ corresponds the waiting, cellular, WiFi and D2D action.
- l denotes the location of MS.
- u is the data type.
- k is the size of data to be transmitted.
- $\mathcal{H}$ denotes the locations of mobile helpers.

State Transition Probability

State Transition Probability

$$P(s'|s,a) = P(l'|l) \cdot \prod_{h \in \mathcal{H}} P(h'|h) \cdot P(k'|l,u,k) \tag{4}$$

$$P(k'|l,u,k) = \begin{cases} 1, & k' = k - \nu_a \text{ } and \text{ } a \in A(l,u) \\ 0, & otherwise \end{cases} \tag{5}$$

$$P(l'|l) = \begin{cases} \mu, & l' = l \\ \rho_i, & otherwise \end{cases} \tag{6}$$

where

$$\mu + \sum \rho_i = 1, \quad i \in \{1,2,3,4\} \tag{7}$$

Transition Cost

$$c_d(s, a) = cost(a) = \nu_a \chi_a \quad (8)$$

$$c_{D+1}(s) = penalty(k, u) = k^{(u+1)} \quad (9)$$

Notations

- ν_a denotes the network data rate.
- χ_a is the price to transmit a data unit for action a
- (e.g., $\nu_1 = 0$ and $\chi_1 = 0$ for waiting action).
- The action cost χ_2, χ_3 and χ_4 are incurred by the usage of cellular, WiFi, and D2D networks at each time slot, respectively.
- For failed data transmissions (i.e. $k > 0$ when $d > D$), we set the penalty cost function in (9).

Value Iteration Method

Objective Function

$$\min_{\pi\in\Pi} E_s^{\pi}\left[\sum_{d=1}^{D} c_d(s,\pi_d(s)) + c_{D+1}(s)\right] \tag{10}$$

Value Function

$$V_d^*(s) = \min_{a\in\mathcal{A}(l,u)} Q_d(s,a) \tag{11}$$

$$\begin{aligned} Q_d(s,a) = \nu_a\chi_a + \sum_{l',h'\in\mathcal{L}} P(l'|l)\cdot\prod_{h\in\mathcal{H}} P(h'|h) \\ \cdot V_{d+1}^*(l',u,(k-\nu_a),\mathcal{H}') \end{aligned} \tag{12}$$

Value Iteration

$$V_d^n(s) = \min_{a\in\mathcal{A}(l,u)} \sum_{s'\in S} P(s'|s,a)[c_d(s,a,s') + V_{d+1}^{n-1}(s')] \tag{13}$$

Hybrid Delayed Tolerant Offloading Algorithm

Algorithm 1 Hybrid Delayed Tolerant Offloading Algorithm

Planning Phase
Initialize data type u and $\mathcal{H}$ with locations of MHs
Initialize $V_d^0(s)$ with Eqs. (8) and (9)
repeat
  for $d \in \mathcal{D}$, $l \in \mathcal{L}$, $k \in \mathcal{K}$ **do**
    compute $V_d^n(s)$ using Eq. (13)
    compute $rsd_d^n(s) = \|V_d^n(s) - V_d^{n-1}(s)\|$
  end for
until $rsd_d^n(s) < \epsilon$
return Best policy $\pi_d^*(s)$
Running Phase
Set $d := 1$ and $k := K$
while $d \leq D$ and $k > 0$ **do**
  Get the locations of MS and MHs and set action $a := \pi_d^*(s)$
  if $k > \nu_2 \times (D - d) \times \kappa(u)$ **then** $k := k - \nu_2$ **else** $k := k - \nu_a$ **endif**
  $d := d + 1$
end while

Performance metrics

Consider three performance metrics.

1. *Total cost*. The total network cost spent by MS during the data transmission process.
2. *Offloading ratio*. Percentage of mobile data that is offloaded to WiFi and D2D networks.
3. *Completion time*. The average time that MS uses to receive the complete data from remote cloud.

Compare with three existing offloading schemes.

- *Optimal Delayed WiFi offloading scheme (D3).* Prediction based cellular data offloading uses WiFi network;
- *Non-Delayed WiFi offloading scheme (ND3).* Data transmission is switched between WiFi and cellular network;
- *Non-Delayed WiFi/D2D offloading scheme (ND4).* WiFi network is used whenever available; D2D communication is used when inequation $k < \nu_2 * (D - d)$ is satisfied. Otherwise, cellular network is used.

Meanwhile, *Non-Offloading scheme (NO)* is used for comparison.

Numerical results

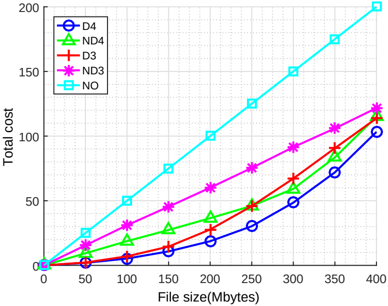

Figure 2: Total cost versus data size K.

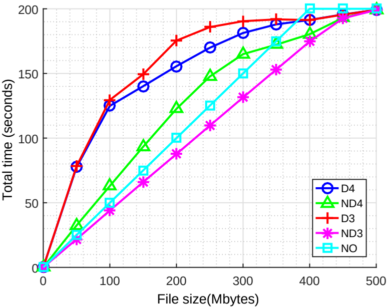

Figure 3: Total time versus data size K.

Numerical results

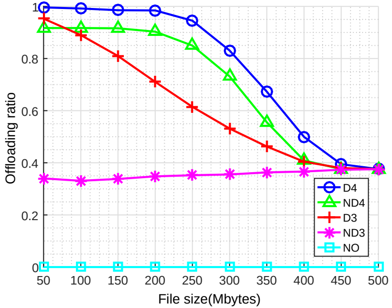

Figure 4: Offloading ratio versus data size K.

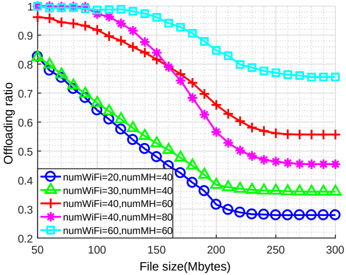

Figure 5: Offloading ratio versus data size K.

Conclusions

- We considered the hybrid offloading network, where data traffic originally transferred by cellular network can be offloaded to WiFi and D2D networks.
- Given that the WiFi network has high connection speed but low coverage area and D2D network can help offloading data where WiFi network is not deployed, the hybrid offloading model can effectively reduce data traffic in cellular network.
- The simulation results show that our proposed scheme can achieve a minimal total cost as compared to existing offloading schemes.

Thank you