Analytical proof of the real case scenario of Cooperative Mobile Web Browsing

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This document shows an analytical proof of the achievable results using the Cooperative Mobile Web Browsing for the real case scenario with overlap. We assume that the web browsing traffic is following an ON-OFF model. The air interface of a mobile device is in active state when a mobile device is downloading the webpage and in idle state when the user is reading the downloaded contents. The Download/Idle state switch of the air interface of a mobile device can be illustrated as Fig 1. We consider a system with a number of mobile device J. The individual mobile device switches between downloading and reading (idle). A mobile phone is reading (idle) during a time interval which is exponential distributed with intensity γ, the mobile device is in download state during an exponentially distributed time interval with intensity μ. This is a typical way to model ON-OFF traffic which is also called pseudo-random traffic.

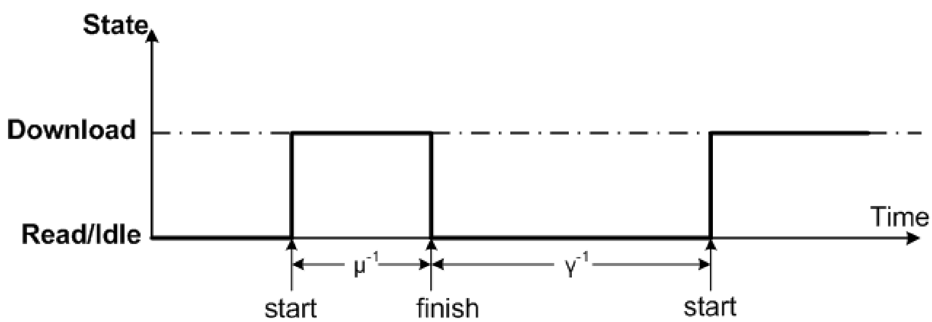

Fig. 1. Every mobile device is in either idle/read or download state, and behaves independent of all other mobile.

We use the number of downloading mobile devices to represent the system state. The system state transition diagram can be illustrated by Fig. 2. The explanation of the state transition diagram is as following: *state* 0 means no mobile device is active i.e., there are J mobile devices in idle state. Since we assume the mean time of the mobile device staying idle state is γ^{-1} with exponential distribution, the intensity of at least one mobile device starting downloading is $J\gamma$. At *state* 1, the system can have two possible transitions: either one more mobile device starting downloading or the downloading mobile device finishing downloading. The intensity of the mobile device finishing downloading is μ. The intensity of one more mobile device starting downloading is $(J-1)\gamma$. The detailed theory can be referred to [1]. Based on state transition diagram Fig. 2, the relation of state probability can be expressed as

$$\begin{aligned} J\gamma \cdot p(0) &= \mu \cdot p(1) \\ (J-1)\gamma \cdot p(1) &= 2\mu \cdot p(2) \\ \cdots \quad & \quad \cdots \\ (J-i-1)\gamma \cdot p(i-1) &= i\mu \cdot p(i) \\ (J-i)\gamma \cdot p(i) &= (i+1)\mu \cdot p(i+1) \\ \cdots \quad & \quad \cdots \\ 1\gamma \cdot p(i) &= J\mu \cdot p(J) \end{aligned} \tag{1}$$

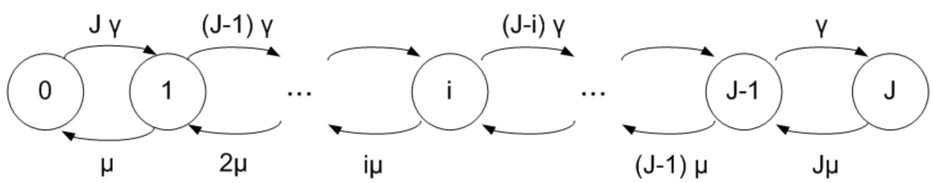

Fig. 2. Every mobile device is either idle/read or download state, and behaves independent of all other mobile devices.

From Eq. 1, we can express all state probabilities by $p(0)$:

$$\begin{aligned} p(1) &= p(0) \cdot \binom{J}{1} \cdot (\frac{\gamma}{\mu})^1 \\ p(2) &= p(0) \cdot \binom{J}{2} \cdot (\frac{\gamma}{\mu})^2 \\ \cdots \quad & \quad \cdots \\ p(i) &= p(0) \cdot \binom{J}{i} \cdot (\frac{\gamma}{\mu})^i \\ p(i+1) &= p(0) \cdot \binom{J}{i+1} \cdot (\frac{\gamma}{\mu})^{i+1} \\ \cdots \quad & \quad \cdots \\ p(J) &= p(0) \cdot \binom{J}{J} \cdot (\frac{\gamma}{\mu})^J \end{aligned} \tag{2}$$

As the total sum of all probabilities must be equal to one, there is

$$1 = p(0) \cdot \left\{ 1 + \binom{J}{1}(\frac{\gamma}{\mu})^1 + \binom{J}{2}(\frac{\gamma}{\mu})^2 + \ldots + \binom{J}{J}(\frac{\gamma}{\mu})^J \right\}.$$

From this we obtain $p(0)$ and letting $\beta = \gamma/\mu$, we get the state probabilities:

$$p(i) = \frac{\binom{J}{i} \cdot \beta^i}{\sum_{j=0}^{J} \binom{J}{j} \beta^j}. \tag{3}$$

Eq. 3 is the Engset-distribution. For the scenario here, $p(1)$, $p(2)$, ..., $p(J)$ means the probability that 1, 2, ..., J mobile devices are downloading, respectively.

So in the proposed cooperation web browsing, the idle mobile devices can help the downloading mobile devices. Assume the traditional average downloading time is T_{down} seconds, there are J mobile device in the cooperation system. So for example, in *state 2* only two mobile device is downloading, then the other $(J - 2)$ mobile device can help these two downloading mobiles. How long the other $(J-1)$ devices can help depends on how long the system stay in *state* 2. In other words, if the system state change, for example the system transits to *state 3*, then the situation becomes that three mobile devices download for themselves, the rest $(J-3)$ mobiles help these three mobiles. Assume the single mobile device downloading data rate is C_{MD} bits/s, the actual downloading rate is dependent on the system state. For example, when the system is in *state 2*, the actual downloading rate would be $\frac{J}{2}C_{MD}$ bits/s. To calculate the average downloading time for cooperative web browsing,

$$T_{down}^{coop} = T_{down} \cdot \sum_{i=1}^{J} \frac{i}{J} P_N(i). \tag{4}$$

where $P_N(i)$ is the normalized downloading state probability, which is given by

$$P_N(i) = \frac{p(i)}{\sum_{i=1}^{J} p(i)} \qquad 1 \le i \le J.$$

Fig. 3 gives the download time versus the number of cooperating mobile phones. The parameters used for the plot are:

- Reading time = 39.7 s
- Webpage size = 350 KB
- Data rate = 500 Kbps

The two lower bounds ($1/J$ and $R = \frac{T_{down}}{T_{down}+T_{read}}$) are also given. $1/J$ would be the download time if all neighboring mobile phones would act *altruistically* with a perfect scheduling. The *real* download time is larger than the lower bound curves due to the overlapping of the web requests. The plot in Fig. 3 have been obtained using $\gamma^{-1} = 10$ *sec* and $\mu^{-1} = 40$ *sec*.

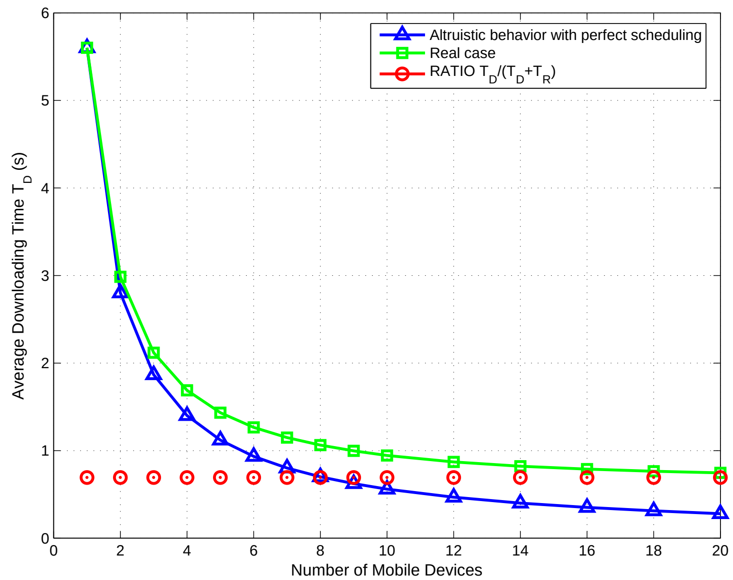

Fig. 3. *Download Gain*: Download time versus number of cooperating entities for the altruistic case (triangles), non-overlapping cooperative case (circles), and overlapping cooperative case (boxes).

References

1. V. B. Iversen. Teletraffic engineering and network planning.