Throughput-Outage Tradeoff of Wireless One-Hop Caching Networks with Affiliation

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Contents

1 Introduction

This is the course report of the class wireless communication and mobile network.I focus on the project with a topic" Throughput-Outage Tradeoff of Wireless One-Hop Caching Networks with Affiliation". I did it as a PRP project. And after PRP I went on to do this work. In general, Compared to the complex modeling, the cumbersome calculation is the most important problem. This paper will show you some important calculation results and steps to help you understand how I get the results. And some image and theorem will be taken in to help you to understand the result.This reporter will introduce my work from several sections such as Background and Motivations, Basic Definition, Two Boundary Results, Model and Problem Formulation, Summary and Future Work.

2 Background and Motivation

As we know, the smart phone is more and more. Today, almost people has one even more mobile device. So the users need more bandwidth to transmit data. But the bandwidth is limited. We have to develop our technique to increase bandwidth. What's more we can build more base stations. But both of two solution is ineffective and too expensive. So we consider to use the caching work. Which means we can get our data from the others device. This makes the storage to work as bandwidth. A good news is that our phone's storage up to 128GB. This makes this method meaningful. There is also an important things is that realistic network user's relationship are evolving over time. We may build a relationship with the same interest. So the affiliation network is necessary to be considered.

Static network has disadvantages that it can not reflect evolutionary properties. So it is a little unrealistic .Besides we can find an improvement in cache when we consider evolution. This is the first time to study the evolution of network outage and throughput tradeoffs. I want to observe the impact to the tradeoff under the affiliation

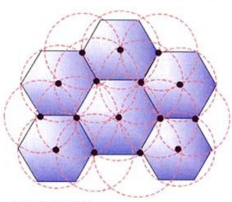


Figure 1: Cellular network

3 Basic Definition

Outage: A user node in a period of time the throughput is expected to be 0, called the point in outage, the ratio of the points in outage for all user

$$p_0 = \frac{1}{n}E[N_0] = \frac{1}{n}\sum_{u\in U} P(E[T_u|f,G] = 0)$$

Throughput: The amount of data transferred between users per slot. (The file is composed of packets)

$$T_u = \sum_{v:(u,v)\in A} c_{u,v} l\{f_u \in G(v)\}$$

Outer Bound: The upper limit of the throughput associated with the outage. (Transmission interference limit)

Innner Bound: The lower limit of the throughput associated with the outage. (File requirements limit)

4 Boudary results

4.1 Outer Bound

case1:

$$T^*_{sum} \le T^{ub}_{sum}(g) = \frac{16}{\Delta^2} \cdot k \cdot c \cdot H(\gamma-1,1,n)[(1-p^{lb}(g)^{(1+\frac{2}{3}\Delta^2)g})\frac{n}{g}]$$
$$\text{when: } g = \Theta(m^\alpha) = \rho m^\alpha$$

case2:

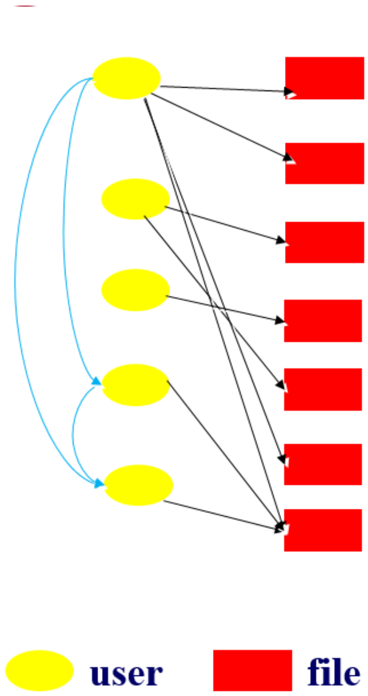
$$T = \frac{c}{\alpha}M^{-\gamma}\frac{n^{-\alpha}}{m^{-\alpha}} + o(\frac{n^{-\alpha}}{m^{-\alpha}})$$
$$\text{when: } 1-(\frac{Mn}{m})^{1-\gamma} \le p \le 1$$

After adding evolution analysisNumber of files has resulted in a small increase in the impact of Throughput. In some case, Evolution of the file growth ratio is high, the Throughput increase. Number of users has little effect.

4.2 Inner Bound

$$T = C \cdot \frac{1}{\gamma^3}\frac{1-2g_c(m)^{1-\gamma}}{g_c(m)}$$
$$\text{when: } p_0 = 2^x(1-\frac{x}{2^{\frac{x}{g_c(m)M}}})$$
$$\text{for: } g_c(m) = \frac{x}{log2\frac{x}{1-\frac{p_0}{2^x}}} \qquad x = \frac{m\gamma}{E[n_2(t)]}$$

After adding evolution analysis, Number of files has resulted in a small increase in the impact of Throughput. Evolution of the file growth ratio is high, the Throughput increase.Number of users has little effect.



$G(Q, E)$

Fix integers $c_q, c_u, s > 0$, and let $\beta \in (0, 1)$.

At time 0, $G_0(Q, E)$ consists of the subset Q of the vertices of $B_0(Q, U)$, and two vertices have an edge between them for every neighbor in U that they have in common in $B_0(Q, U)$.

At time $t > 0$:

(Evolution of Q) With probability β:

(*Arrival*) A new node q is added to Q.

(*Edges via Prototype*) An edge between q and another node in Q is added for every neighbor that they have in common in $B(Q, U)$ (note that this is done after the edges for q are determined in B).

(Edges via evolution of U)
With probability $1 - \beta$:

A new edge is added between two nodes q_1 and q_2 if the new node added to $u \in U$ is a neighbor of both q_1 and q_2 in $B(Q, U)$.

(Preferentially Chosen Edges) A set of s nodes $q_{i_1}, \ldots, q_{i_s}$ is chosen, each node independently of the others (with replacement), by choosing vertices with probability proportional to their degrees, and the edges $(q, q_{i_1}), \ldots, (q, q_{i_s})$ are added to $G(Q, E)$.

Figure 2: Affiliation Network

5 Network Model

5.1 Affiliation Model

In the B graph, there are user and files. Produced according to a certain probability of users and files, for example, when a time slot coms it produced a document, the new document will inherit the degree uniformly based on how many degrees of old files. The users do the same evolution. Then focus on the G graph.The first few steps are same as the B graph. The main step is the last one.Simply if two users have edges with the same files. They will have a edge with each other in the G graph.

5.2 Caching Network Model

The caching network consists of files and users in a two-dimensional plane. Files cache in the users' device, the user who does not have their own documents to make a request to the neighbor to find the files they wanted. The device has a range to propagate, and will be interfered when a transmitting happening around at the same time.

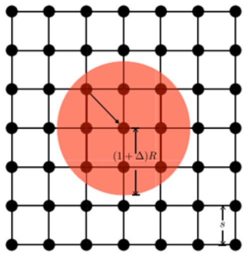


Figure 3: Caching Network

5.3 Parameter

There are there important parameters. The number of users. The number of files. And the ratio of file increase. We can find the degree of the users and the files in the B graph according to the existing paper. Like the theorem in the PPT shows. We have an obvious premise that in the real world, the files is more that users. And its increasing ratio is also larger than users. So α is much more than 1. It was used many times when I have to derived formula.

n: Number of users

M: Number of files

$\alpha(\gamma)$: Ratio of File increase

For the bipartite graph B(Q,U) generated after n steps,almost surely, when n $\to \infty$,the degree sequence of nodes in Q (resp. U) follows a power law distribution with exponent $\alpha = -2 - \frac{c_q\beta}{c_u(1-\beta)}(\alpha = -2 - \frac{c_u(1-\beta)}{c_q\beta})$, for every degree smaller than n^γ, with $\gamma < \frac{1}{4+\frac{c_q\beta}{c_u(1-\beta)}}(\gamma < \frac{1}{4+\frac{c_u(1-\beta)}{c_q\beta}})$

6 Problem Formulation

6.1 Outer Bound

In the Outer Bound, the user's degree in the B graph effects transfer speed.The file's degree in the B graph effects file requirements. They both conform to the power law ,and the exponent has shown, so we can take it in to the equition. We make a parameter $g_R(m)$, it means All the points within a transmission radius. Using the gr we can find some constraints to get the outer bound.

In the Fig4. if A is transmit to B ,and C is a point which is recive data. Use the triangle theorem,we can find any two point that is in transmitting have to have a deltaR distance. In other words, any transmiting point have to have a half of delta R to guarantee its transimit can happened without interference

$$d(j,l) \geq d(k,j) - d(k,l) \geq (1+\Delta)R - d(k,l) \geq (1+\Delta)R - R = \Delta R$$

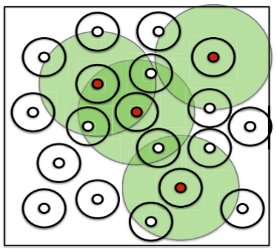


Figure 4: Transmitting Radius

Known that the transmiting point have to satisfied the safe distance, The distance between transmissions gives the upper limit of the number of transmissions to get the tradeoff between throughput and outage. we can look at the picture. Each points has a sector around it, and in a given region, this distance make the number of the sector fixed, and we think this points are all in transmitt. So we can calculate the throughput. Here's a processing technique. Instead to find the exactly result of Throughput ,we get the sum, and then we get the average to Simplified operation. In the formular we notice the last factor.

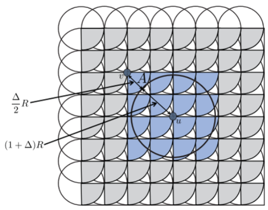


Figure 5: Number of transmiting points

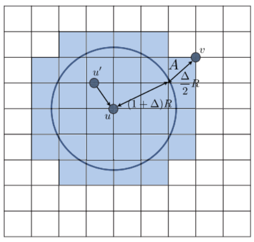


Figure 6: Safe distance of the transmiting points

And we get

$$T^*_{sum} \leq T^{ub}_{sum}(g) = \frac{16}{\Delta^2} \cdot k \cdot c \cdot H(\gamma - 1, 1, n)[(1 - p^{lb}(g)^{(1+\frac{2}{3}\Delta^2)g})\frac{n}{g}]$$

We can derivate this factor to find the condition that the throughput will be largest, then we have to solve the $g_R(m)$. It is a intermediate parameter. We have to express it by the parameter we have ,so it has 3 relationship with files number.

for$(1-p^{lb}(g)^{(1+\frac{2}{3}\Delta^2)g}$

$$1.g = o(m^{\alpha})\ 2.g = \omega(m^{\alpha})\ 3.g = \Theta(m^{\alpha}) = \rho m^{\alpha}$$

First one and the second one will make the outage to 1, means there is little transmition happening. In the third cases we can find when the bigeer than gamma will have the same trend with throughput, which means the R is large.And we get two differen results in different condition.

$$1.\rho > \frac{1}{M}, \gamma\uparrow, T\uparrow$$
$$2.\rho < \frac{1}{M}, \gamma\uparrow, T\downarrow$$

Then we consider the other case, when the files is too many, and the formular is change to this. In this case every transmition condition is satisified and will transimit together. But this case the outage is too big and it can not decrease to 0. Which means its will cause most points in 0 throughput.

$$T_{sum} = C\cdot E[L]$$
$$\leq C\sum_{u=1}^{n}\sum_{f=1}^{Mn}P_r(f) = Cn\frac{H(\gamma,1,Mn)}{H(\gamma,1,m)}$$
$$\text{when } 1-(\frac{Mn}{m})^{1-\gamma}\leq p\leq 1$$

6.2 Inner Bound

In the Inner Bound, the the user's degree in the B graph effect transfer speed,the file's degree in the B graph effect file requirements, the user's degree in the G graph effect the propagation.We make a parameter $g_c(M)$. It means all the points in a cluster . Using the gr we can find some constraints to get the inner bound. Users can only find files in the cluster and transmit unless they have an edge in G graph.

Before we start we have to discuss an important things. The files cache in the users' device, but how do they cache? So we have a optimal caching to make the user has a highest probility to find their request.We assume that l_u is the active link and $p_c(u)$ is the expectation that the users find the request successfully. Then we can get:

$$p_u^c = E[l_u] = P(F_{gc(m)}^u)$$
$$= \sum_{f=1}^{m}P_r(f)((1-(1-P_c(f))))^{ME[n_2(t)\frac{m}{gc(m)-M}]}$$
$$= \sum_{f=1}^{m}\frac{f^{-\gamma}}{H(\gamma,1,n)}((1-(1-P_c(f))))^{ME[n_2(t)\frac{m}{gc(m)-M}]}$$

Summation all the $P_c(f)$ is 1, having this two condition we can use the lagrange function to find the optimal caching.

$$L(P_c,\xi) = \sum_{f=1}^{m} P_r(f)(1-P_c(f))^{Mg-M} + \xi'(\sum_{f=1}^{m} P_c(f) - 1)$$

The formulas are the result of the simplification:

$$P_c(f = \frac{1+\epsilon-(\epsilon-1)\cdot 2^{\frac{1}{\epsilon}}}{\epsilon})$$
$$\text{when } \epsilon = \frac{M\cdot E[n_2(t)\frac{g_c(m)}{m}]-M-1}{\gamma}$$

We assume that w is the number of potential links in a cluster, and we think the throughput is the speed multiply with the expectation of active links. According to this, we can get the expression like:

$$\overline{T}_{sum} = C\cdot E[L] = k\cdot E[n_1(t)]\cdot \frac{E[total\ number\ of\ clusters]\cdot P(W>0)}{K}$$
$$= K\cdot cH(\gamma,1,n)\cdot \frac{E[total\ number\ of\ clusters]\cdot P(W>0)}{K}$$

To maximize the Throughput, we have to maximize the potential links. Then we use a probability formula to change the target into two simple problem.

$$To\ MaximizP[W] \geq \frac{E[W]^2}{E[W^2]}$$
$$MinimizeE[W^2]\ and\ MaximizeE[W]$$

After taking the $P_c(f)$ to consider, we can make the Inner Bound condition which is that file requesting become the most important constrain.,and we get the $P(W>0)$

$$P(W>0) = \frac{2\gamma-2}{(\gamma-2)^2}\frac{1-2g_c(m)^{1-\gamma}}{1-g_c(m)^{1-\gamma}+2\gamma-2}$$

and after taking other parameters and inequality transformation we get the final result:

$$T = C\cdot \frac{1}{\gamma^3}\frac{1-2g_c(m)^{1-\gamma}}{g_c(m)}$$

Outage is easily to think but not easy to count. As we can see , the outage's condition is shown like:

$$p_0 = P(no\ file) + P(no\ link) - P(no\ file\ and\ no\ link)$$
$$p_0 = A + B - AB$$
$$\text{when } A = \prod_1^{g_c(m)M}(1-P_c(f))\ B = \prod_1^{g_c(m)}(1-x^{-\gamma}))$$

But I cannot find a way to simplify and use the G graph. In the end of the evolution, some points will have the most degree and this is like a base station. That is not what we want. So I change to use the B graph to effect the transmit way, if you have a interest in some file then you can transmit it. So the B case is not important the A is the main condition we have to concern. And we get the outage.

$$p_0 = \prod_1^{g_c(m)M} [1 - P_c(f)]$$
$$= 1 - \frac{1}{\epsilon}[1 - \frac{1+\epsilon-(\epsilon-1)\cdot 2^{\frac{1}{\epsilon}}}{\epsilon}]^{g_c(m)M-1}$$
$$= \frac{\epsilon-1}{\epsilon}(\frac{(\epsilon-1)2^{\frac{1}{\epsilon}}-1}{\epsilon})^{g_c(m)M-1}$$

$$Finally\ we\ get\ p_0 = 2^x(1 - \frac{x}{2^{\frac{x}{g_c(m)M}}})$$
$$when\ x = \frac{m\gamma}{E[n_2(t)]}$$

And we notice the T include the $g_c(m)$,and we find the $g_c(m)$ has the different monotonicity with the Throughput

Finally, we have result of Inner Bound but it is too complex and I have to ues the matlab to find the parameter's relationship with the throughput. We can find both m and gamma can make the Throughput increase.

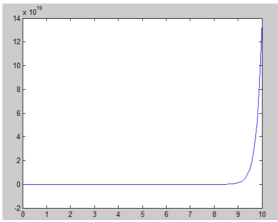


Figure 7: T-γ

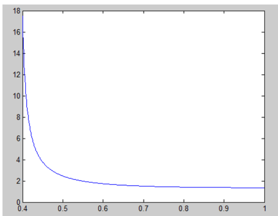


Figure 8: $g_c(m) - x$

7 Summary

After adding evolution analysis,in the case that propagation radius large

1.Number of files has resulted in a small increase in the impact of Throughput

2.Evolution of the file growth ratio is high,the Throughput increase

3.Number of users has little effect.

8 Future Work

Gap :
the gap between inner bound and outer bound is not close.

Complete :
the cases which is talked are not Include all the circumstances.

Experiment:
the results need some experiment to support

9 Reference

[1] Silvio Lattanzi,D Sivakumar "Affiliation Networks", in STOC2009 December 13,2010

[2]Mingyue Ji, Giuseppe Caire, Andreas F.Molisch "Throughput-Outage Tradeoff of Wireless One-Hop Caching Networks " in IEEE TRANSACTIONS ON INFORMATION THEORY Vol 61, NO.12,December 2015