PROJECT TITLE: CONTENT CACHING IN MCPS

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1 Scope of the project:

We would like to work on stochastic geometry-based approaches for the modeling, and deriving analytical expressions of different types of hit probability metrics for content caching in clustered wireless Device to Device (D2D) networks. Although the expression for cache hit probability with Base Stations (BS) modelled as Homogeneous Poisson Point Process are available in literature, but similar expressions for Poisson Cluster Process remain largely unexplored. Particularly, we would like to focus on deriving expressions for Cache-Aided Throughput [1] and/or Density of Successful Receptions [2] in Matern Cluster Process (MCP). [3] derived expression for cache hit probability which was defined as probability that at least k neighbors are in the communication range of a typical node. This definition of cache hit probability ignores the interference from neighbouring users, which is quite important in D2D networks. [4] derives expression for hit probability for 2 cases when the user is served by – (a) closest BS having requested file or (b) BS with requested file and maximum instantaneous received power. But it does not consider D2D communication with the cached content of other users and only considers the communication between users and BS's. We would like to extend these techniques to develop expressions for Cache-Aided Throughput and/or DSR for the cooperative [5] case where the user request's file from the cached content of neighbouring device or, as a last resort, from the BS. We will make appropriate assumptions on the caching model and then would try to generalize the existing expression for HPPP to MCP using techniques from [1, 2, 5]. If time permits, we will also try to verify the results using simulations.

2 System Model:

Firstly, we will start with a simple model for D2D communication and consider the non-cooperative case and where the communication happens only between users. Then we will generalize our expression to more complicated system model:

1. We have a parent point point process Φ_p and intensity λ_p, which points denotes the cluster center.

2. The daughter point process is taken to be uniform Poisson Point Process λ_u on a disk of radius R_d i.e. the user devices are distributed as a Matern Cluster Process.

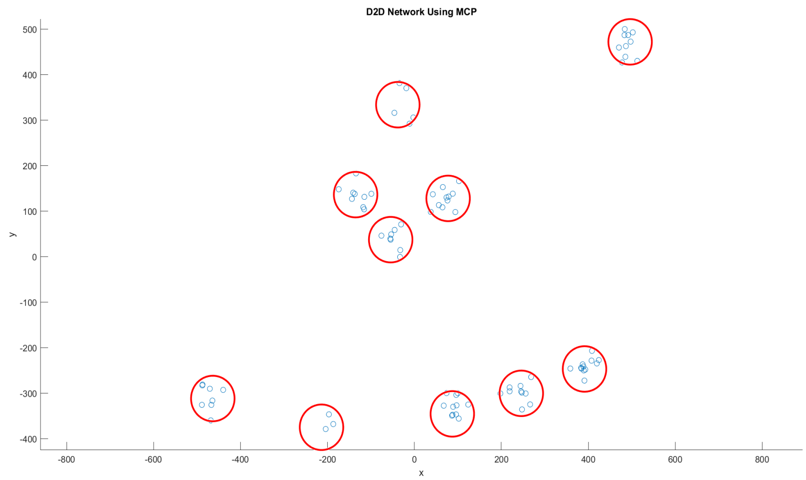

Figure 1: Illustration denoting BSs and devices (dots)

3. Each device acts as a possible transmitter or receiver, independently with probability ρ and $1-\rho$ respectively. The transmitting devices are transmitting with power P_d.

4. Each cluster has a finite content library $\mathcal{F}_x = [f_1^x, f_2^x, \cdots, f_{N_x}^x]$ for each cluster centered at Φ_x and $x \in \Phi_p$, with possibly different files. The N_x files are sorted in decreasing order of their popularity, which is modelled using Zipf(γ_x) distribution, where γ_x denotes the skewness of the Zipf distribution. Each receiver requests a file f_i^x with probability q_i^x, which is given by

$$q_i^x = \frac{i^{-\gamma_x}}{\sum_{j=1}^{N_X} j^{-\gamma_x}}$$

5. The transmitting devices have a local cache memory of size $M < N_x$. Each unit of memory carries a single file. Each file has a size L.

6. Each device independently caches the file(s) f_i^x with probabilities p_i^x, where the index i corresponds to the popularity index of the file.

7. For a representative cluster centered at x_0, P_{i,x_0}^{hit} denotes the conditional hit probability conditioned on the user requesting the i^{th} most popular file($f_i^{x_0}$).

$$P_{i,x_0}^{hit} = \mathbb{P}(\text{SINR}_{i,x_0} > \beta)$$

where β is the minimum threshold for a successful transmission and

$$\text{SINR}_{i,x_0} = \frac{P_d g_z ||\mathbf{z}||^{-\alpha}}{\sigma^2 + I_{inter} + I_{intra}}$$

where $\mathbf{z}$ is the location of service device, based on closest association, g_z is the random Rayleigh fading coefficient (exponentially distributed), I_{inter} and I_{intra} denote the inter cluster and intra cluster interference respectively.

8. The total hit probability $P_{x_0}^{hit}$ is given as:

$$P_{x_0}^{hit} = \sum_{i=1}^{N_{x_0}} q_i^{x_0} P_{i,x_0}^{hit}$$

The hit probability can be maximized by choosing the optimum values of catching probabilities of each file.

9. The Density of successful receptions (DSR) [2] is defined as the density of receptions which result in a successful communication.

$$\text{DSR} = \rho\lambda_u \sum_{i=1}^{N_{x_0}} q_i P_{i,x_0}^{hit}$$

10. The cache aided throughput [1] $\mathcal{T}$ (for the representative cluster) is the average number of requests that can be successfully and simultaneously handled by the local caches per unit area.

$$\mathcal{T} = \rho\lambda_u \left[\sum_{i=1}^{N_{x_0}} p_i q_i \cdot 1 + \sum_{i=1}^{N_{x_0}} p_i (1 - q_i) P_{i,x_0}^{hit} \right]$$

We will derive expressions for cache aided throughput for the above model as explained in next section. Then we will slightly modify our model and consider more complicated case where multiple BS's are also present in the same cluster and both BSs as well as devices are catching the data. We will consider co-operative catching [5, 6] in this case and solve for optimal catching probabilities in devices as well as base stations. The modified system model is:

1. In addition to the previous model, there will be base stations distributed as MCP having the same parent process as that of the user's. The base stations are distributed around the cluster center as a finite homogeneous(size R_d) PPP of intensity λ_b independent of user point process given the parent points.

2. The transmitting powers of the base stations is P_b

3. The size of the base station cache is given as $K < N_x$.

4. We will try to obtain expressions for the coverage probability, hit probability, DSR, and the cache aided throughput for cooperative caching.

3 Approach to the Solution:

We will take the following approach:

1. For calculating the hit probability:

   (a) We will first try to compute the hit probability for each file P_{i,x_0}^{hit}

(b) For this we will condition on the number of devices containing the file $f_i^{x_0}$
(c) This can be converted to an integral on the distribution of the serving distance from the origin
(d) Now the $\mathbb{P}(\text{SINR}_{i,x_0} > \beta)$ can be compute as g_z would follow an exponential distribution
(e) Now we will compute the Laplace transform of the intercloud and the intracloud interference [7].

2. For calculating the cache aided throughput and DSR:

   (a) We will consider 2 cases, self caching and device catching.
   (b) For the self catching case, our device will be served with a probability 1 and for other device, it will be served with hit probability (computed above).
   (c) The summation will be done over all files weighed by their respective request probabilities q_i^x.
   (d) For computing the DSR, we will weigh the coverage probability of each file with the density of file receivers.

3. For calculating the hit probability in 2nd case:

   (a) Here we need to consider 3 cases, catching from a device, catching from a base station and if the base station does not contain the requested file, it will retrieve it from the network, which will add an extra delay(D_0).
   (b) The coverage probability for retrieving the file from the BS and from nearby devices would need to be calculated. Now, here we can make 2 assumptions here which changes the expression of interference. If we assume that out-of-band D2D communication system, i.e., there is no cross-interference between the cellular network and D2D communication, then the computing coverage probability for both cases is straightforward (from above). If this is not the case (both use same band), then obtaining Laplace transform might be difficult. We will modify this assumption based on mathematical tractability.

4. As a final step, we will simplify the obtained expression's (if needed) and draw design insigts and/or formulate them as optimization problem for determining the optimal caching distribution. If time permits, we will also try to verify the results using simulations

References

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