Impact of Correlated Mobility and Cluster Scalability on Connectivity of Wireless Networks

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ABSTRACT

We propose the *correlated mobile k-hop clustered networks model* to implement correlated node movements and scalable clusters. We divide network states into three categories, i.e., *cluster-sparse state*, *cluster-dense state* and *cluster-inferior dense state*, and achieve the critical transmission range for the last two states. Furthermore, we find that correlated mobility and cluster scalability are closely related with each other and the impact of these two properties on connectivity is mainly through influencing network state transition.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design—*Wireless Communications*

General Terms

Theory and Performance

Keywords

Network Connectivity, Correlated Mobility, Cluster Scalability, Critical Transmission Range.

1. INTRODUCTION

Since the seminal work [2] done by Gupta *et al.*, there has been a great interest in the scaling analysis of network performance and many follow-up works have explored the *asymptotic connectivity* of wireless networks. But most of these works focus on stationary and flat networks, where nodes are independently and uniformly distributed. Since mobility and clustering property have been found to improve various aspects of network performance, it is interesting to explore the impact of correlated mobility and cluster scalability on network connectivity. In [3], Wang *et al.* studied the critical transmission range for various networks under different mobility models, but it doesn't achieve real clustering effect. Nevertheless, it provides the major motivation for our work.

SIGMETRICS'14, June 16–20, 2014, Austin, Texas, USA.
ACM 978-1-4503-2789-3/14/06.
http://http://dx.doi.org/10.1145/2591971.2592012.

In order to understand the nature of correlated node movements and node spatial heterogeneity, and explore their mutual interactions, implications and impact on the asymptotic connectivity, we propose the *correlated mobile k-hop clustered networks model* to take into consideration both the *correlated mobility* and *cluster scalability.* We adopt the correlated mobility model in [1] to implement the group mobility, and suppose that there are $n^\alpha (0 < \alpha \leq 1)$ cluster heads and $n^\gamma (0 < \gamma \leq 1)$ clusters, each with a radius of $R = \Theta(n^\beta)(\beta \leq 0)$ in the whole network $\mathcal{O}$, which is assumed to be a unit torus. The cluster radius can scale with the number of nodes n, and with different values of β we can implement cluster scalability.

To investigate the impact of correlated mobility and cluster scalability on connectivity in correlated mobile k-hop clustered networks when the number of nodes $n \to \infty$ and study the influence that α, β and γ has on network performance, we divide the network states into three categories according to the value of these three parameters, the *cluster-sparse state* $(\alpha + 2\beta < 0)$, *cluster-dense state* $(\alpha + 2\beta \geq \frac{1-\gamma}{k})$ and *cluster-inferior dense state* $(0 \leq \alpha + 2\beta < \frac{1-\gamma}{k})$. We prove the critical transmission range to be $\sqrt{\frac{\log n}{k\pi n^\alpha}}$ for cluster-dense state and $\sqrt{\frac{[k(\alpha+2\beta)+\gamma]\log n}{k\pi n^\alpha}}$ for cluster-inferior dense state.

2. NETWORK MODEL

2.1 Network Deployment

In this part, we illustrate the initial network architecture deployment before cluster members begin to move. We suppose there are n cluster-member nodes and n^α cluster-head nodes in a unit square $\mathcal{O}$, where the *cluster head exponent* $0 < \alpha \leq 1$. The cluster-head nodes are *uniformly and independently distributed* in $\mathcal{O}$, which is assumed to be a torus in $\mathbb{R}^2$ to avoid border effects. Different from the network model in [3], cluster-member nodes are grouped into m clusters where $m = n^\gamma$ and the *cluster exponent* $0 < \gamma \leq 1$. Each cluster region is centered around a logical center (*home point*) and has a circular shape with radius R as $R = \Theta(n^\beta)$, where the *cluster radius exponent* $\beta \leq 0$. The home points are *uniformly and independently distributed* in $\mathcal{O}$ and the cluster-member nodes are *uniformly and independently distributed* in their belonging cluster regions, each of which has a circular area of πR^2. We assume that each cluster is comprised of $\varpi = \frac{n}{m} = n^{1-\gamma}$ cluster members. We also assume n^α and n^γ to be integers for convenience.

2.2 Correlated Mobility

After deploying the initial network architecture, the cluster heads will remain stationary while the cluster members will move. We illustrate our *Correlated Mobility Model* as follows:

Correlated Mobility Model: After the network deployment, home points and cluster members will move. Time is slotted into k time slots. At the beginning of each time slot, each home point will *uniformly and independently* choose a position within the unit torus $\mathcal{O}$ and then each cluster member will *uniformly and independently* choose its location in its corresponding cluster region. In the rest of each time slot, the home points and cluster members will remain stationary.

2.3 Cluster Scalability

After introducing the system model, we will present the unique characteristic of our network, ***cluster scalability***. As we can see, the cluster radius scales with n by assuming $R = \Theta(n^{\beta})$ where $\beta \leq 0$. Hence, when β is small (with large absolute value), the cluster size will be small and clusters are sparsely distributed in $\mathcal{O}$. While the cluster region will become relatively large when β is large (with small absolute value), which leads to densely distributed clusters.

This is the qualitative illustration of cluster scalability and we should also provide a quantitative definition. We compare the average coverage of cluster heads, $\frac{1}{n^{\alpha}}$, with the cluster region $\pi R^2 = \Theta(n^{2\beta})$ and give the following three cases:

(C1). *Cluster-sparse state* (member-dense state).

When $\pi R^2 = o(\frac{1}{n^{\alpha}})$, we have $\alpha + 2\beta < 0$. The cluster size is sufficiently small compared with the average coverage of each cluster head and clusters are sparsely distributed in the whole network $\mathcal{O}$. Besides, the member density of each cluster $d = \frac{\varpi}{\pi R^2} = \Theta(n^{1-2\beta-\gamma})$ is large. Thus, this is also the member-dense state and the clustering property is fairly dominant. Each cluster can be regarded as an entirety because cluster members stay so close and move so consistently.

(C2). *Cluster-dense state* (member sparse state).

In contrast to the previous case, we have $\alpha + 2\beta \geq \frac{1-\gamma}{k}$ in this state and can further have $\pi R^2 = \omega(\frac{1}{n^{\alpha}})$. The cluster size is relatively large, clusters are densely distributed in $\mathcal{O}$ and they might intersect with each other. The member density d is relatively small, and hence this is the member-sparse state and there is almost no substantial clustering. In this case, every cluster member performs more like an independent node.

(C3). *Cluster-inferior dense state* (member-inferior sparse state).

In this case, we have $0 \leq \alpha + 2\beta < \frac{1-\gamma}{k}$ and still have $\pi R^2 = \omega(\frac{1}{n^{\alpha}})$. It is the transitional state between the cluster-sparse state and cluster-dense state. In this case, we can neither regard members in the same cluster as a whole nor treat them as totally independent nodes. Instead, we group the nodes into sub-clusters.

3. MAIN RESULTS AND INTUITIONS

We summarize our main results as follows.

(C2). *Cluster-dense state* $(\alpha + 2\beta \geq \frac{1-\gamma}{k})$.

We have $r_c = \sqrt{\frac{\log n}{k\pi n^{\alpha}}}$, where $0 < \alpha \leq 1, 0 < \gamma \leq 1$.

(C3). *Cluster-inferior dense state* $(0 \leq \alpha + 2\beta < \frac{1-\gamma}{k})$.

We have $r_c = \sqrt{\frac{[k(\alpha+2\beta)+\gamma] \log n}{k\pi n^{\alpha}}}$, where $0 < \alpha \leq 1, 0 < \gamma \leq 1$.

4. CONCLUSION

We illustrate our results in Figure 4.1. Although the three parameters all have an influence on network state transition, thus affecting network connectivity, their separate functions are different. α can serve as a centralized network coordinator because this parameter can adjust r_c from the perspective of the whole network. In contrast, β controls network in a distributed manner, since it influences cluster radius R and node density ϖ on the cluster level. γ can control the number of clusters as well as node density, so it regulates the network both in centralized and distributed manner.

With *correlated mobility* and *cluster scalability*, we can achieve network connectivity with a smaller critical transmission range than that in an i.i.d. mobility network. **Thus, we can save transmission power by bringing *correlated mobility* and *cluster scalability* into the networks.**

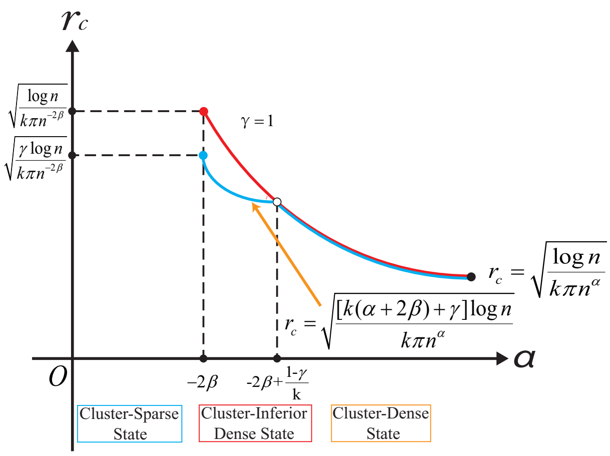

Figure 4.1: Impact of α, β and γ on Network State Transition. ***Network state transition is jointly affected by α, β and γ. Among the three factors, α is the most influential, and r_c monotonically decreases with α. While γ can on some level shape the curve, the impact of β on r_c is mainly through determining the transition points.***

5. REFERENCES

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