Delay and Throughput Scaling for Supportive Two-Tier Networks

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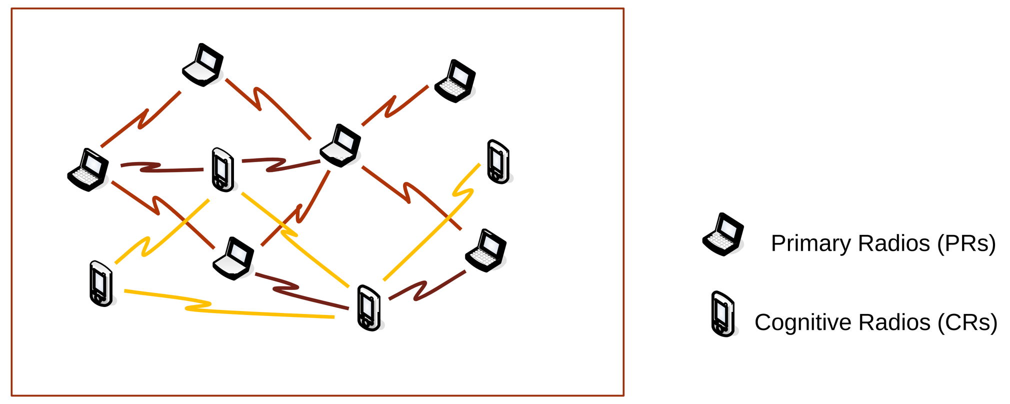
Introduction

1. Consider a two-tier network in a unit area: A static primary tier and a mobile secondary tier.
2. Assume that the secondary tier is willing to help the primary tier to route its packets, while the primary tier is not.
3. Investigate the throughput and delay scaling laws of the two tiers.



System Model

1. Network model
   - The primary nodes are distributed according to P. P. P. of density n and randomly grouped into one-to-one source-destination (S-D) pairs.
   - The secondary nodes are distributed according to P. P. P. of density m and know the location of primary TXs.
   - The relationship between m and n is given by

$$m = n^{\beta}$$

2. Channel model

$$g(r) = r^{-\alpha}$$

3. Interaction model
   - The secondary nodes act as relays for the primary nodes while they have their own packets to transmit.
4. Transmission rate and throughput
   - The transmission rate of the k-th primary S-D pair

$$R_p(k) = \log\left(1 + \frac{P_p(k) g(\| X_{p,tx}(k) - X_{p,rx}(k) \|)}{N_0 + I_p(k) + I_{sp}(k)}\right)$$

   - The transmission rate of the l-th secondary S-D pair

$$R_s(l) = \log\left(1 + \frac{P_s(l) g(\| X_{s,tx}(l) - X_{s,rx}(l) \|)}{N_0 + I_s(l) + I_{ps}(l)}\right)$$

   - Throughput per S-D pair $\lambda(n)$ and sum throughput $T(n)$
5. Fluid model and delay $D(n)$

Main Results

1. We propose a coexistence scheme for the primary and secondary tiers.
   - The primary tier uses a typical time-slotted adjacent-neighbor transmission protocol.
   - The secondary tier chooses its protocol according to the given primary protocol.
2. For the primary tier, we have
   - Throughput per S-D pair $$\lambda_p(n) = \Theta\left(\frac{1}{\log n}\right)$$
   - Packet delay
     - The i.i.d. mobility model $$D_p(n) = \Theta(1)$$
     - The random walk mobility model $$D_p(n) = \Theta\left(\frac{1}{S}\right)$$
3. For the secondary tier, we have
   - Throughput per S-D pair $$\lambda_s(m) = \Theta(1)$$
   - Packet delay
     - The i.i.d. mobility model $$D_s(m) = \Theta(m)$$
     - The random walk mobility model $$D_s(m) = \Theta\left(m^2 S \log\frac{1}{S}\right)$$

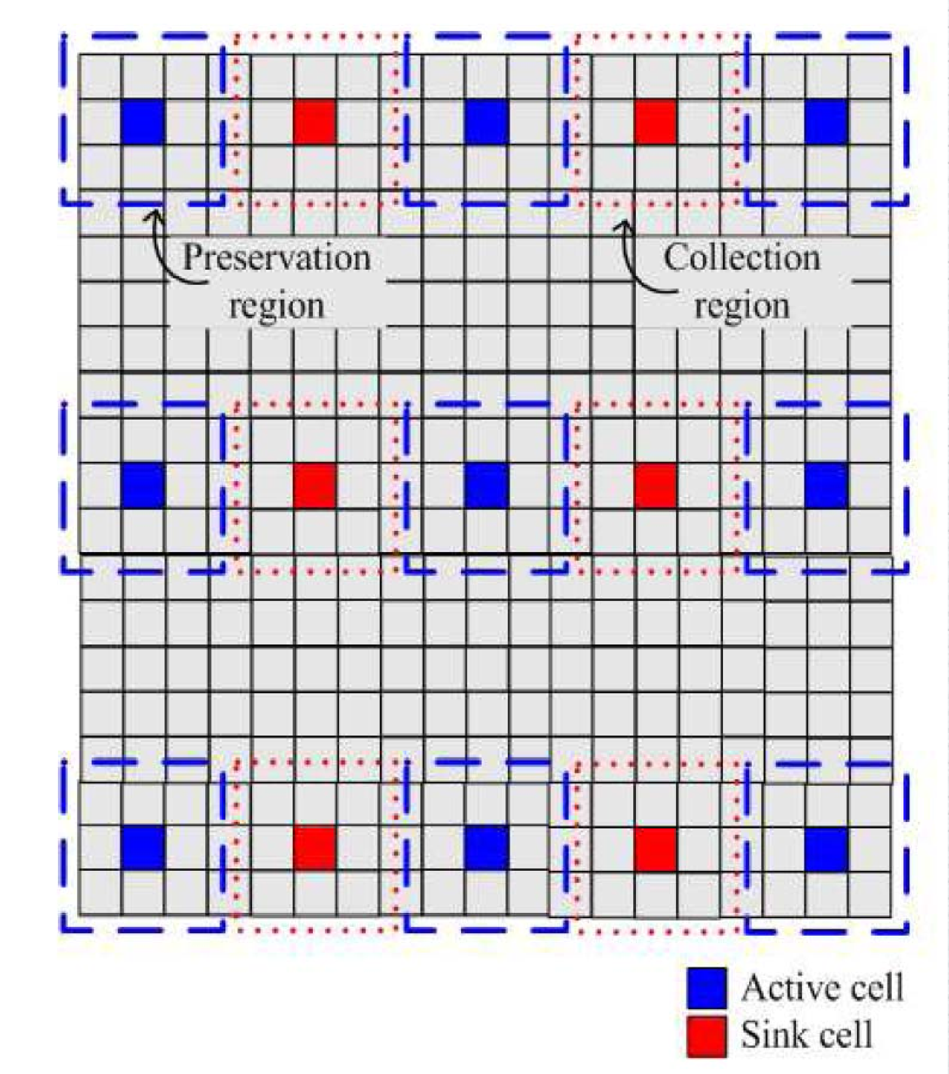


Fig. 1 Preservation regions and collection regions

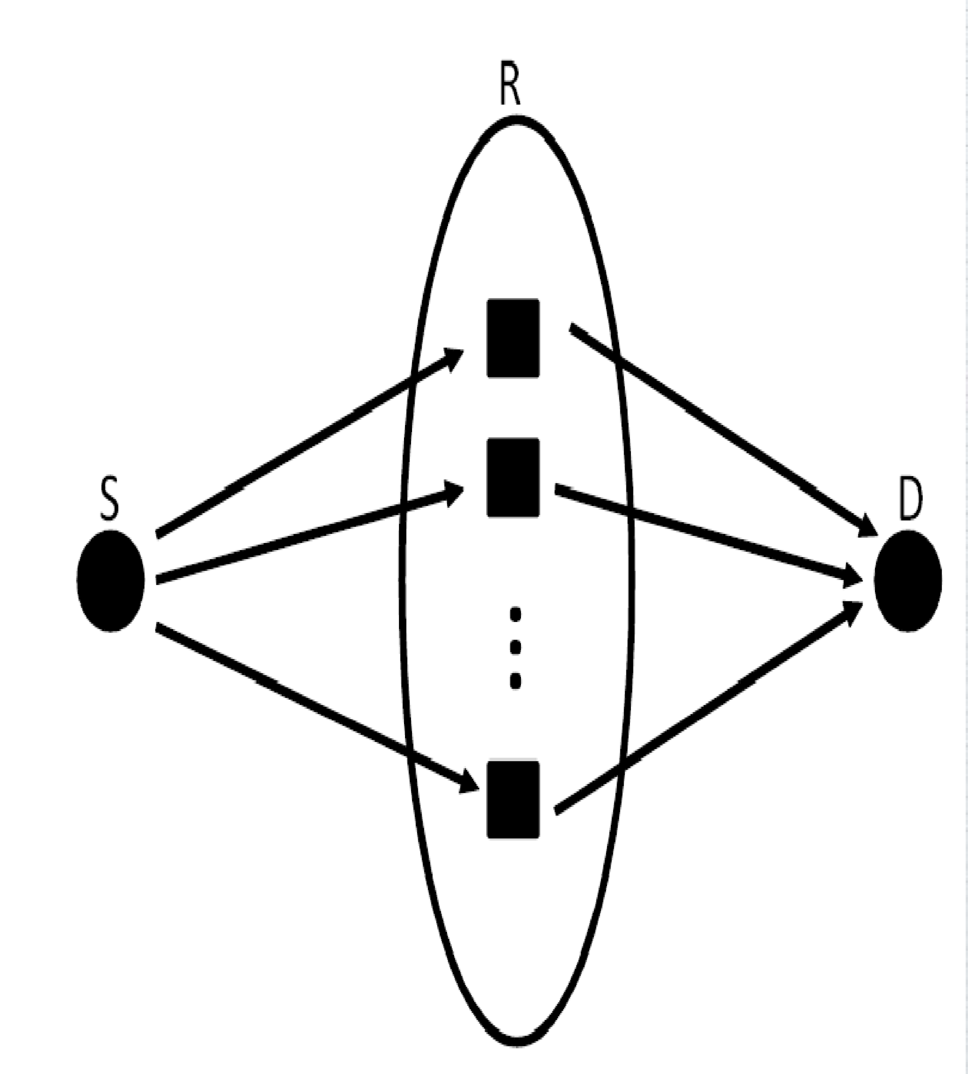


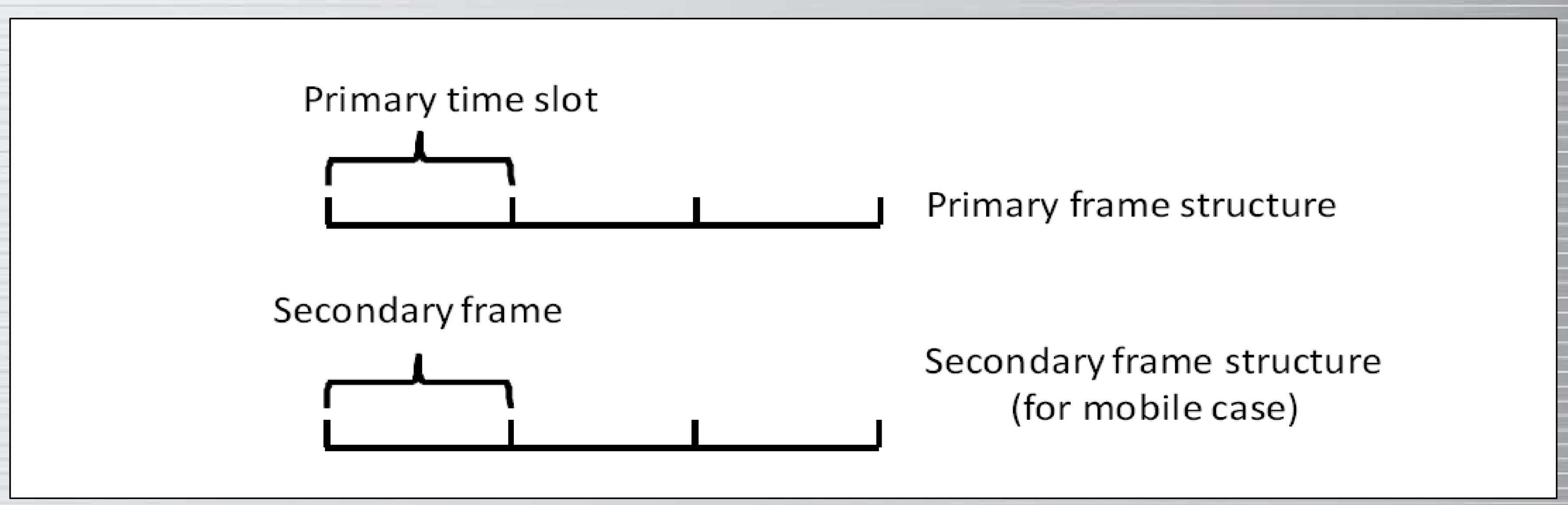
Fig. 2 Illustration of the virtual relay node R

Protocol Design for Primary Tier

1. Divide the unit square into small-square primary cells of area $a_p \geq 2\log n / n$.
2. Group every 64 cells into a cluster and use 64-TDMA for data transmission.
3. When a primary cell is active, the source nodes in it take turns to transmit data to their neighboring cells along their data paths.
4. All packets for each S-D pair are labelled with SNs and handshake mechanism is used for packet reception.

Protocol Design for Secondary Tier

1. Define preservation region
   - If a secondary node is in a preservation region, it is not allowed to transmit packets; instead, it stores the primary packets for future deliveries.
   - If a secondary node is outside a preservation region, it transmits the primary and secondary packets in its buffer.
2. Define collection region
   - If a secondary node is in a collection region, it delivers the primary packets.
   - If a secondary node is outside a collection region, it transmits the secondary packets.



Conclusion

1. We studied the throughput and delay scaling laws for supportive two-tier networks.
2. The primary tier can achieve better throughput and delay scaling laws with the aid of the secondary tier.
3. The secondary tier can achieve the same throughput and delay scaling laws as a stand-alone network.