Heterogeneous Wireless Networks

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The Interoperability of Wi-Fi Hotspots and Packet Cellular Networks - The Impact of User Behaviour

Problem Description

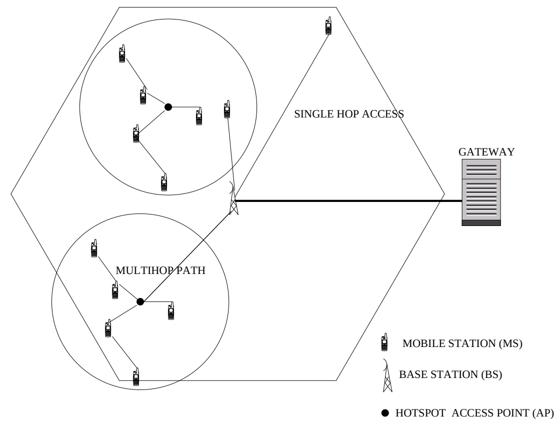


Figure 1: Network Architecture

- A Mobile Node (MN) connects to AP or BS
- Multihop relaying allowed
- AP & BS differ in bandwidth, cost, coverage

User Profiles

- Each mobile node has a **User Profile**
- Different Types of User Profiles
  - Bandwidth Conscious (CLASS 1)
  - Cost Conscious (CLASS 2)
  - Glitch Conscious (CLASS3)
- Study impact of different user profiles on Network peformance
- Will switch between AP and BS based on User Profiles
- Maintaining connectivity is essential

LASS 1 - Bandwidth Conscious User Profi

- Free bandwidth available at a BS or AP sent with beacon advertisements
- Connect to AP or BS offering the highest bandwidth
- eg: Nodes engaged in multimedia traffic.

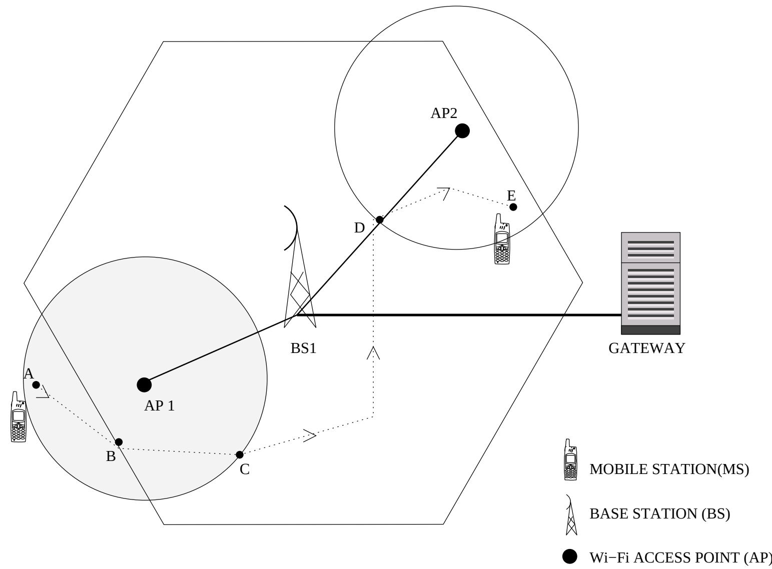
CLASS 2 - Cost Conscious User Profile

- Cost also advertised with beacons
- Switches to a new network if advertised transmission cost is lower
- eg: nodes engaged in non-real time file transfers

CLASS 3 - Glitch Conscious User Profile

- Glitch = interruption in communication on network switching
- Aims to minimize number of glitches
- Strategy : remain connected to the network with larger coverage
- eg: Nodes engaged in voice calls

Moving across a heterogeneous terrain



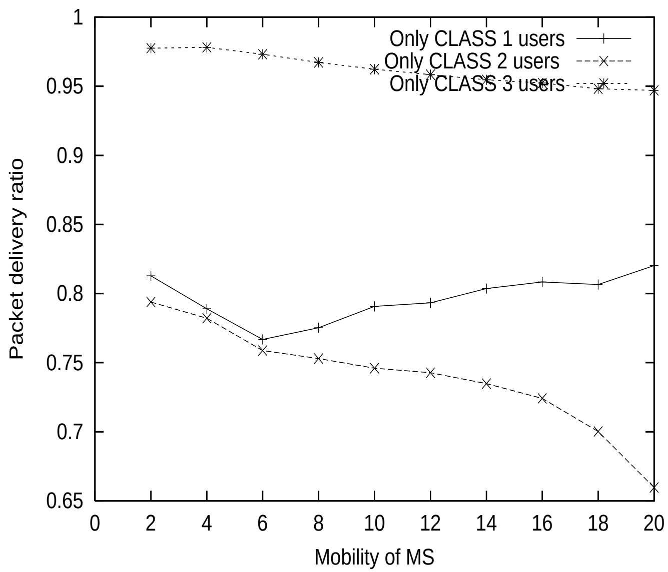
- Total B/W at AP1 & AP2 = 11 Mbps, at BS = 5 Mbps
- Free B/W at AP1 < Free B/W at AP2 and BS
- Free B/W at BS < Free B/W at AP2
- Cost per byte using BS = 4 times that using an AP

Parameters studied

- Studied the following measures of performance
  - Average Packet Delivery Ratio (PDR)
  - Average Cost incurred
  - Average Number of glitches
- Parameters varied
  - Mobility of nodes
  - Number of APs
  - Traffic load
  - Number of nodes

Results

- Simulations with Single Type of Nodes



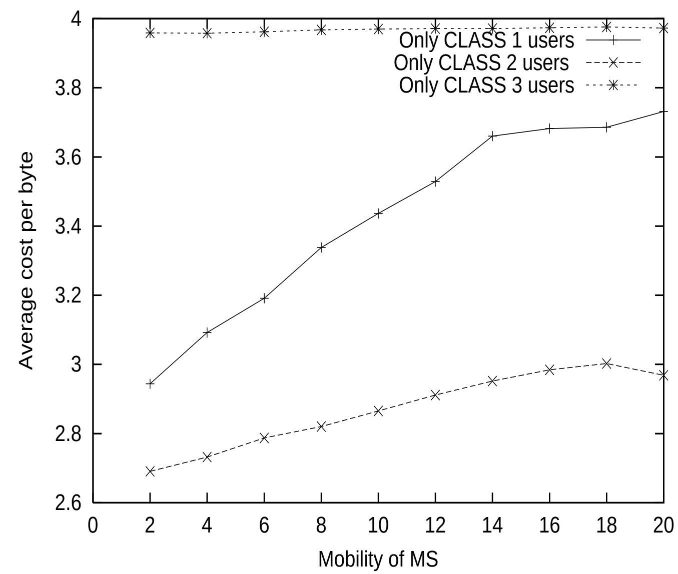


Figure 2: Packet delivery ratio vs Mobility of the MSs

Figure 3: Average cost per byte incurred by an MS vs Mobility of the MSs

Results - continued

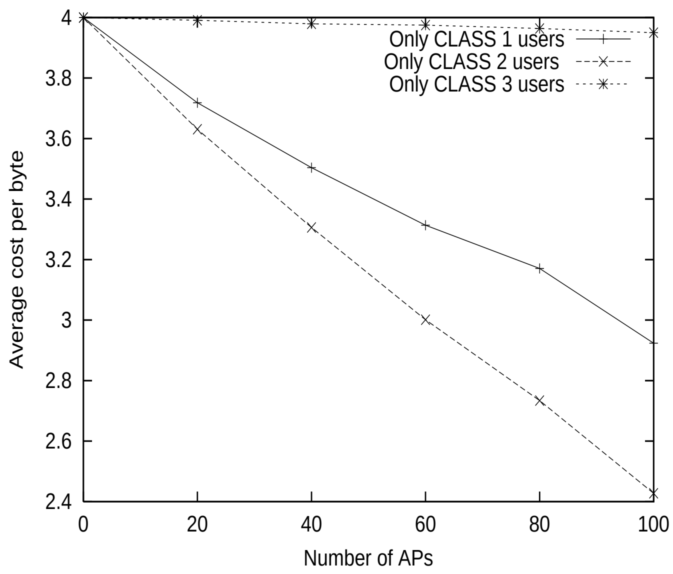


Figure 4: Average cost per byte incurred by an MS vs number of APs

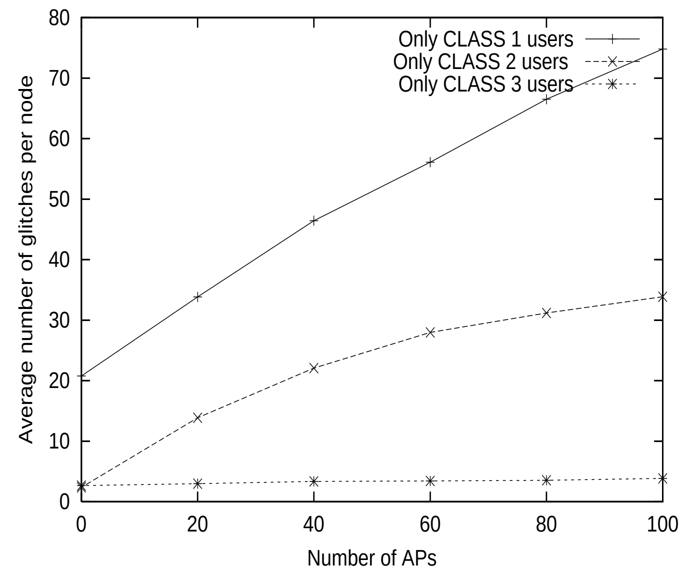


Figure 5: Average number of glitches experienced by an MS vs number of APs

Results - continued

- Equal proportions of all three user profiles - similar trends
- Anomaly - Glitch Conscious User getting higher bandwidth than Bandwidth Conscious User!
- B/W at BS reduced from 5Mbps to 1Mbps, APs made SCNs, increased number of nodes to 500

Results - continued

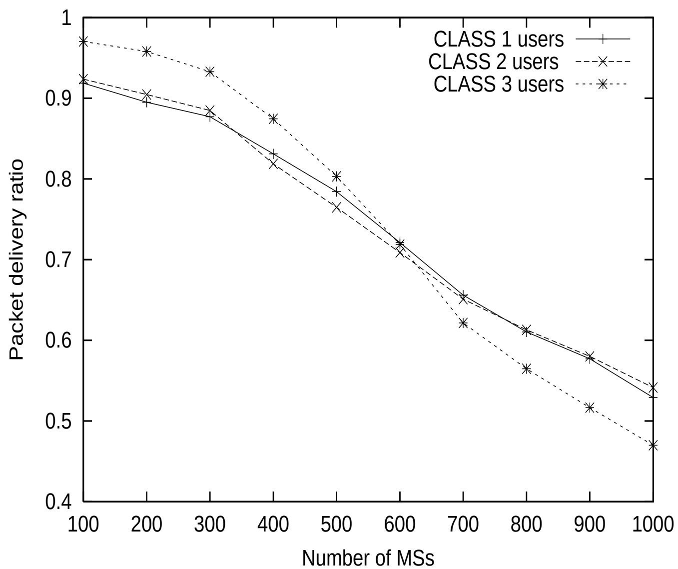


Figure 6: Packet Delivery Ratio vs Number of MSs (SCN, BS with 1Mbps)

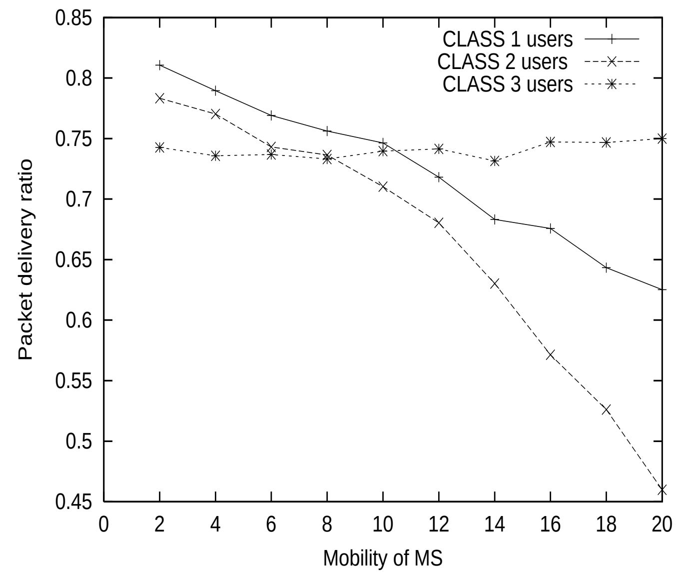


Figure 7: Packet Delivery Ratio vs Mobility of the MSs (SCN, BS with 1Mbps)

Results continued

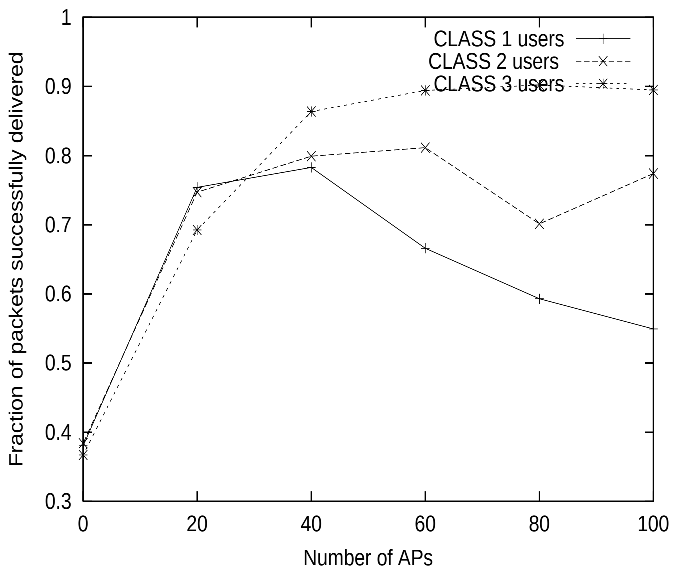


Figure 8: Packet Delivery Ratio vs Number of APs (SCN, BS data with 1Mbps)

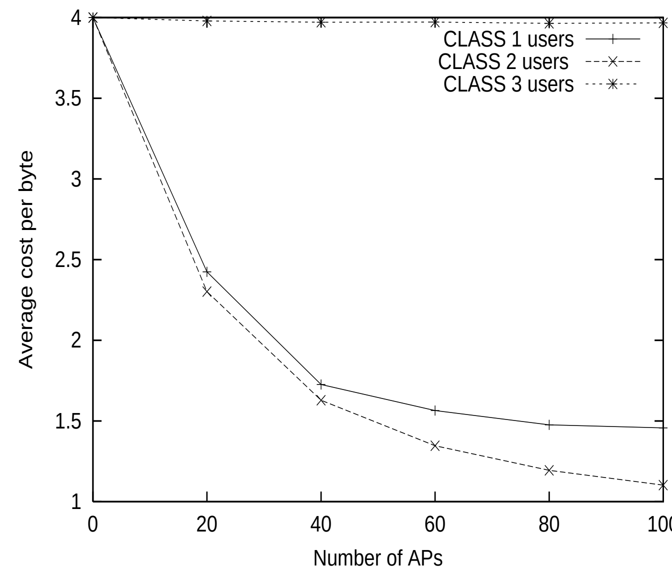


Figure 9: Average cost per byte incurred by an MS vs Number of APs (SCN, BS with 1Mbps)

Capacity Analysis of Random Ad hoc Networks

Problem Description

- N mobile nodes identically distributed in a region with area A_r
- Maximum transmission rate of a node = W bits/second
- What is the maximum feasible throughput $\lambda(N)$ for a node?

Related Work

- P.R. Kumar & P. Gupta (2000) show that $\lambda(N) = c\frac{W}{\sqrt{N\log(N)}}$ is feasible.
- Mobicom 2003 paper analysed throughput with infra structure support: $\lambda(N)$ of the order $\theta(\frac{W}{\log(N)})$
  - Assumption: *N*umber of nodes per AP is bounded
- Implication: *F*easible throughput decreases as N increases

Attempted Result

- Fixed number of APs $\mathbf{K}$
- Maximum $\lambda(N) = \theta(\frac{W}{\sqrt{N\log(N)}})$
- First, we derive the bound without APs

Protocol Model for interference

- Transmission from node i to node j is interference free if
  - $|X_i - X_j| \leq r_T$
  - No other transmitter around j within $(1+\Delta)r_T$ of receiver
- Disk of radius $\Delta\frac{r_T}{2}$ at receiver to be disjoint for simultaneous transmission

Upper Bound on Throughput

- Max number of such disks in $A_r = \frac{4A_r}{\pi\Delta^2 r_T^2}$
- $\therefore$ Max capacity = $\frac{4A_r}{\pi\Delta^2 r_T^2} * W$
- $\frac{\overline{L}}{r_T}$ = mean number of hops
- $\lambda(N) * N * \frac{\overline{L}}{r_T} \leq \frac{4A_r}{\pi\Delta^2 r_T^2} * W$
- $\therefore \lambda(N) \leq \frac{4A_r W}{\pi\Delta^2 r_T \overline{L} N}$
- For connectivity, $r_T \geq \sqrt{\frac{logN}{\pi N}}$
- $\therefore \lambda(N) \leq \frac{4A_r W}{\sqrt{\pi}\Delta^2 r_T \overline{L}\sqrt{N \log N}}$

Lower Bound on Throughput

- Show that $\frac{W}{\sqrt{N \log N}}$ is achievable
- Find a spatial/temporal virtual channel with order $\frac{W}{\sqrt{N \log N}}$ capacity.
- Find a Voronoi Tesselation (V_N) of the region such that
  - Each Voronoi Cell (VC) contains a disk of radius ρ
  - Each VC is contained in a disk of radius 2ρ
- Choose ρ as the radius of a disk of area $\frac{100 A_r \log N}{N}$

Interfering VCs

- Let $r_T(N) = 8\rho(N)$
- $\Rightarrow$ Node can transmit to nodes in its VC or in adjacent VCs only.
- 2 VCs A and B are **interfering** if $\exists$ a point in A within a distance of $(2+\Delta)r_T(N)$ of some point in B.
- Max number of interfering cells = C_1 where $C_1 = \frac{[(2+\Delta)r_T(N)+6\rho(N)]^2}{\rho(N)^2}$
- Every $(C_1 + 1)$ slots, each VC gets 1 interference free slot. (Graph Coloring)

Source $\rightarrow$ Destination

- Y_i = randomly chosen destination of node at X_i
- $(X_i, Y_i)_{i=1toN}$ is *i*.i.d
- Packets sent along the line L_i, joining X_i and Y_i
- Multihop from VC to VC
- Each VC should contain atleast one node

Vapnik Chervonenkis Theorem

If $\mathcal{F}$ is a set of finite VC-dimension $VC - d(\mathcal{F})$ and X_i is a sequence of i.i.d. random variables with common probability distribution P, then $\forall \delta, \epsilon > 0$,

$$\text{Prob}\left(sup_{F \in \mathcal{F}} \left| \frac{1}{N} \sum_{i=1}^{N} I(X_i \in F) - P(F) \right| \leq \epsilon \right) > 1 - \delta \qquad \text{whenever}$$

$$N > \max\left\{ \frac{VC - d(\mathcal{F})}{\epsilon} \log \frac{16e}{\epsilon}, \frac{4}{\epsilon} \log \frac{2}{\delta} \right\}$$

Let us take $\mathcal{F}$ to be set of disks with radius $\rho(N)$.

Atleast 1 node per VC

$$\text{Prob}\left(sup_{D\in\mathcal{F}} \left| \frac{\text{Num nodes in disk D}}{N} - P(D) \right| \leq \epsilon \right) > 1 - \delta$$

$$P(D) = \frac{100 A_r \log N}{N} / A_r$$

Let $\epsilon = \delta = \frac{50 \log N}{N}$

$$\text{Prob}\left(sup_{D\in\mathcal{F}} \left| \frac{\text{Num nodes in disk D}}{N} - \frac{100 \log N}{N} \right| \leq \frac{50 \log N}{N} \right)$$

$$> 1 - \frac{50 \log N}{N}$$

Number of nodes in any VC $\geq \frac{50 \log N}{N}$
$\Rightarrow$ multihop relaying possible.

Number of routes served by a VC

- For every line L_i and VC V,
- Prob (Line L_i intersects V) $\leq C_2\sqrt{\frac{\log N}{N}}$
- Using Vapnik Chervonenkis Theorem, Prob$\left(\text{sup}_{V \in V_N} Num lines intersecting V \leq C_3\sqrt{N \log N}\right) \geq 1 - \delta'(N)$
- $\therefore$ Bound on the traffic to be carried by a cell.

Achieving $\frac{W}{\sqrt{N \log N}}$

- Each VC can transmit at $\frac{W}{C_1+1}$.
- $\lambda(N)$ can be attained if $C_3 \lambda(N) \sqrt{N \log N} \leq \frac{W}{C_1+1}$
  $\Rightarrow \lambda(N) \leq \frac{C_4 W}{\sqrt{N \log N}}$

Presence of K Access Points

- APs handle only non-local traffic.
- Locality $l = 0 \Rightarrow$ completely non-local traffic
- Local load of a node = $l\lambda(N)$
- Traffic to be carried by a VC = $\frac{C_4 W}{l\sqrt{N \log N}}$
- $(1-l)\lambda(N)$ traffic goes to the K APs

Coverage of an Access Point

- Straight line multihop path to AP for non-local traffic.
- h_{AP} = max hops allowed to AP
- $r_{AP} \leq h_{AP} r_T(N)$
- Only nodes within r_{AP} can use the AP.

Load due to the APs

- Consider disks of radius r_{AP} centered around the APs.
- Applying Vapnik Chernovenkis Theorem, we get number of nodes in the coverage of an AP $\leq C_5 \log N$.
- Let AP be located in VC P.
- Non-local traffic of atmost $C_5 \log N$ passes through VC P and its adjacent VCs.
- Extra load on VC P = $C_6(1-l)\lambda(N) \log N$
- Total load on VC P = $C_3 l \lambda(N)\sqrt{N \log N} + C_6(1-l)\lambda(N) \log N$

Capacity achieved

- $\lambda(N)$ can be attained if
  $C_3\lambda(N)\sqrt{N\log N} + C_6(1-l)\lambda(N)\log N \leq \frac{W}{C_1+1}$
  $\Rightarrow \lambda(N) \leq \frac{C_5 W}{l\sqrt{N\log N}+C_7(1-l)\log N}$
  $\lambda(N) = \frac{W}{\sqrt{N\log N}}$

To do

- Verify the result using simulations??
- Add Cellular Base Stations
- Use AP or BS on the basis of the user profile.
- When AP coverages intersect and fixed size.
- Find practical routing protocols which achieve these limits.