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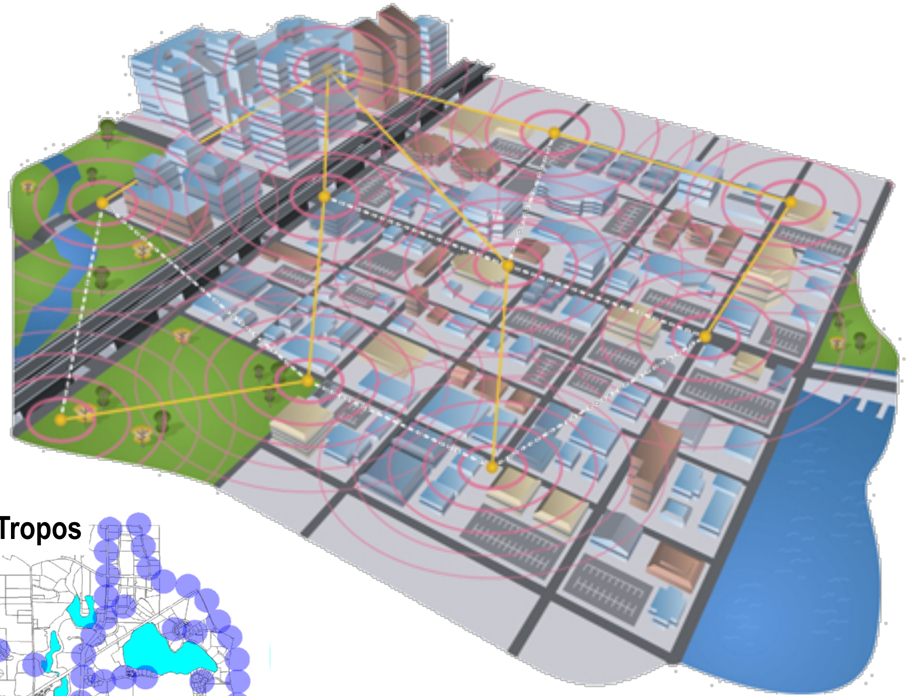
Stiftelsen för internationalisering av högre utbildning och forskning

Outline

- WLAN Spectrum Utilisation Measurement
- Urban-X
  - Channel Assignment
  - Routing, Forwarding and Scheduling
- Summary and future work

Mesh Networks and the Future Wireless Internet

- Wireless Mesh Networks
  - Single hop vs. multihop
  - Part of future wireless internet
  - Broadband for all
    - Urban Mesh Networks
    - Developing regions
  - Deployed in ISM bands
  - Coexistence



Source: Tropos

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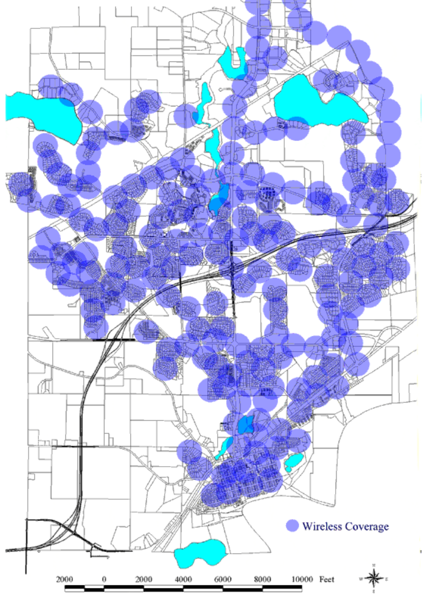


Source: Tropos

Mesh Networks and Interference Problems

- Utilisation of ISM bands
  - Residential WiFi APs, Bluetooth, mesh networks by different operators, microwave ovens, security cameras, remote controls, audio/video senders, etc.

Interference is commonplace and is a more important cause of wireless networking problems than congestion. In the long term this could be reduced by enforcing coexistence criteria via the standardisation committees. However, in the short term there are a lot of radio types in use and the interference problem is predicted to continue to increase. Inner city locations are extremely busy and do exhibit signs of congestion as well as interference. We expect this to be occuring in most large cities of the UK.
- Ofcom survey

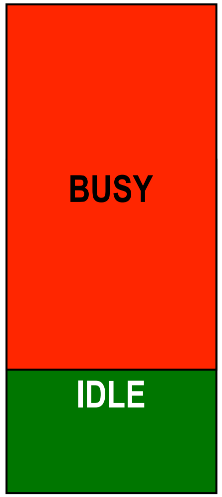
http://www.ofcom.org.uk/research/technology/research/exempt/wifi/wfiutilisation.pdf

Measuring the utilization of IEEE 802.11b/g channels

- Clear Channel Assessment (CCA) is part of IEEE 802.11 MAC
- Can use **`ath5k_hw_reg_rea`** on ATH5K driver to query HAL
  - **`PROFCNT_RXCLR`** = Number of clock ticks the medium was busy due to (CCA)
  - **`PROFCNT_CYCLE`** = Total number of clock ticks

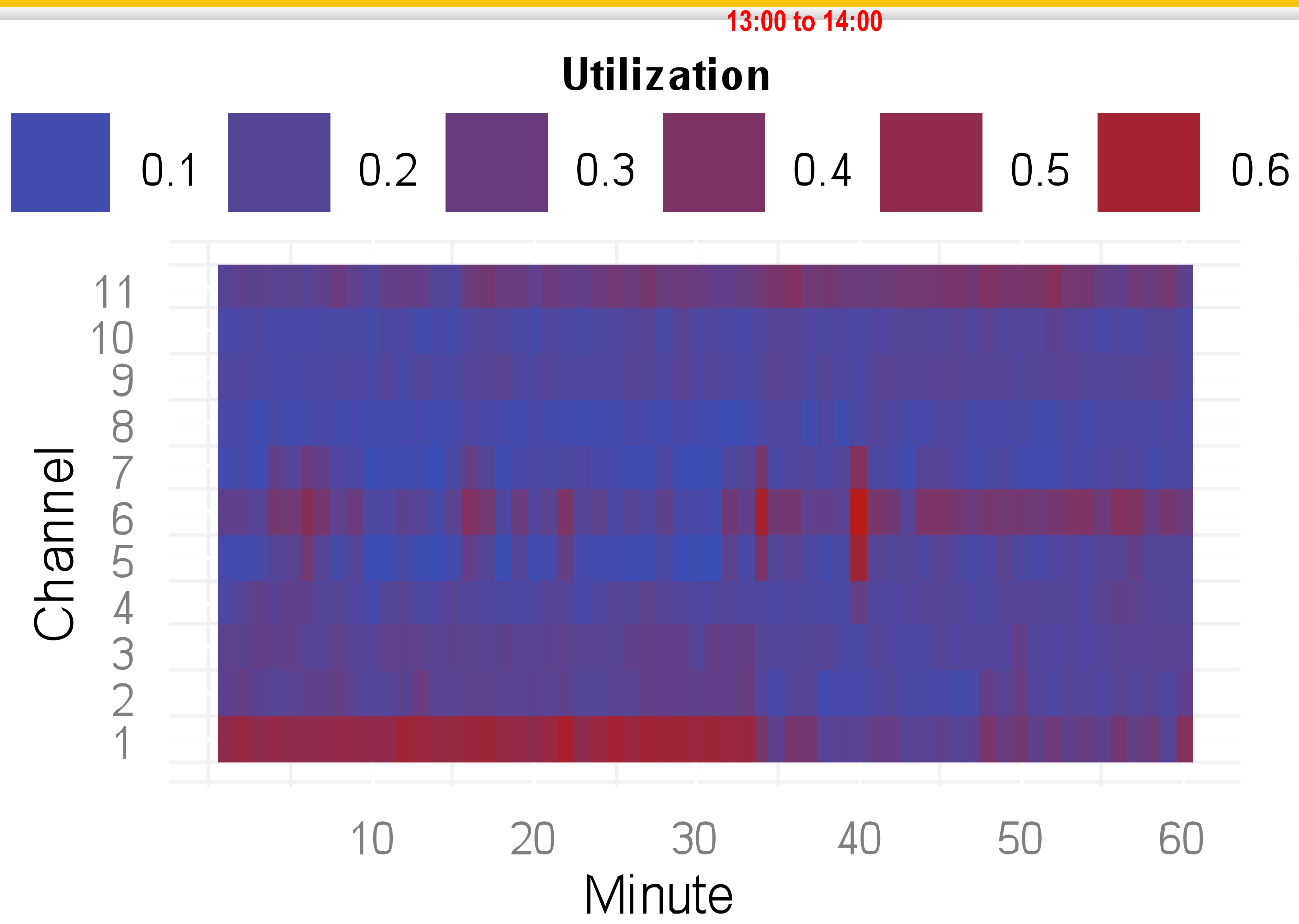
  → **Busy Fraction = `PROFCNT_RXCLR`/`PROFCNT_CYCLE`**
- Spectrum Sensing Algorithm

> **1. Stay on channel *i* for X ms (e.g. 600 ms) and take a sample of busy fraction every Y ms (e.g. 200 ms)**
> **2. Switch channel to *i*=(i+1)% 11. GOTO 1**

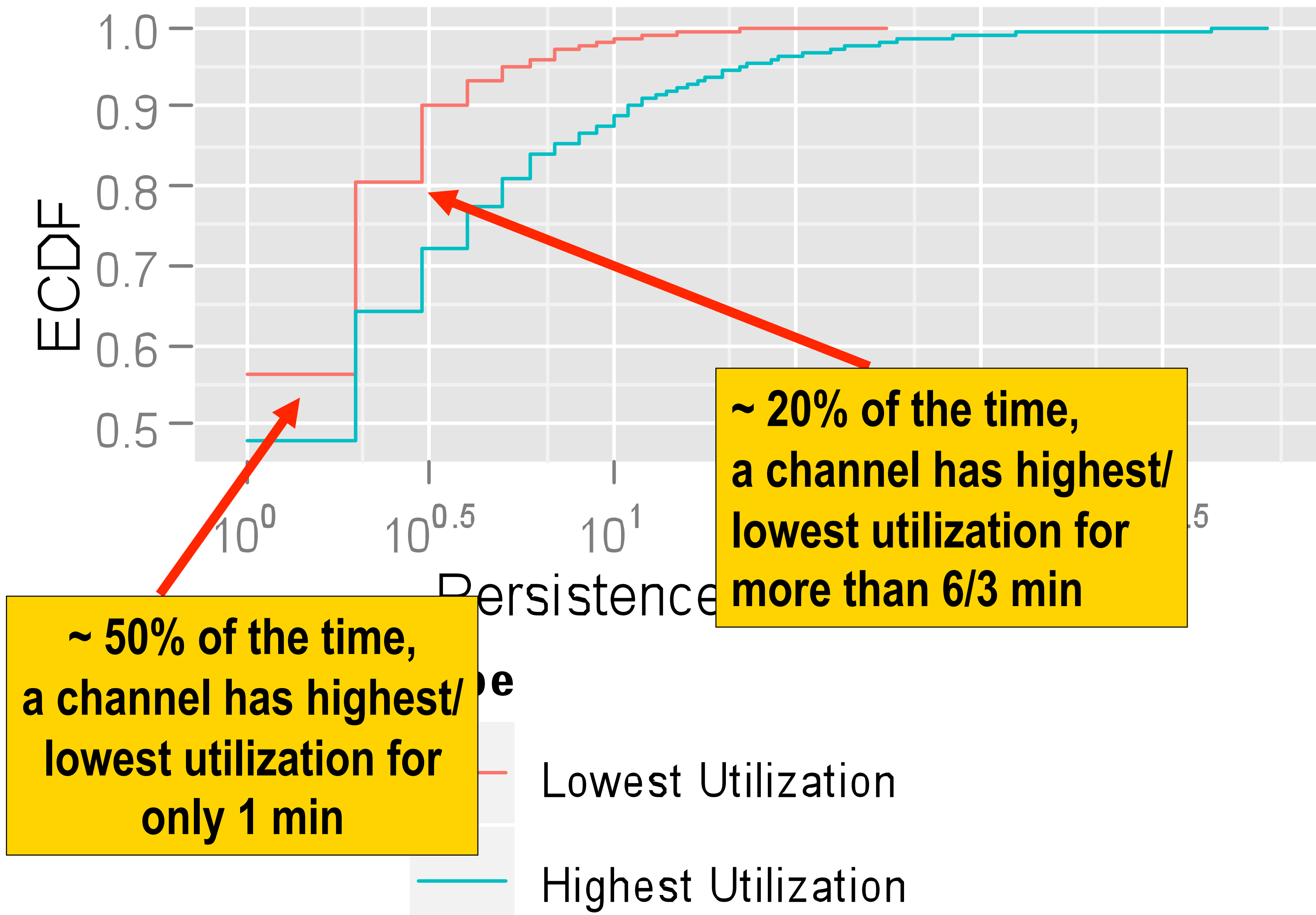


- Measurement campaign ongoing, preliminary results
  - Several moving Taxis in Macao (with GPS), total 23 hours
  - Karlstad University library, total 2 weeks
  - Karlstad residential, 4 days
  - Residential area in Berlin, 3 days
  - Berlin office, 1 day

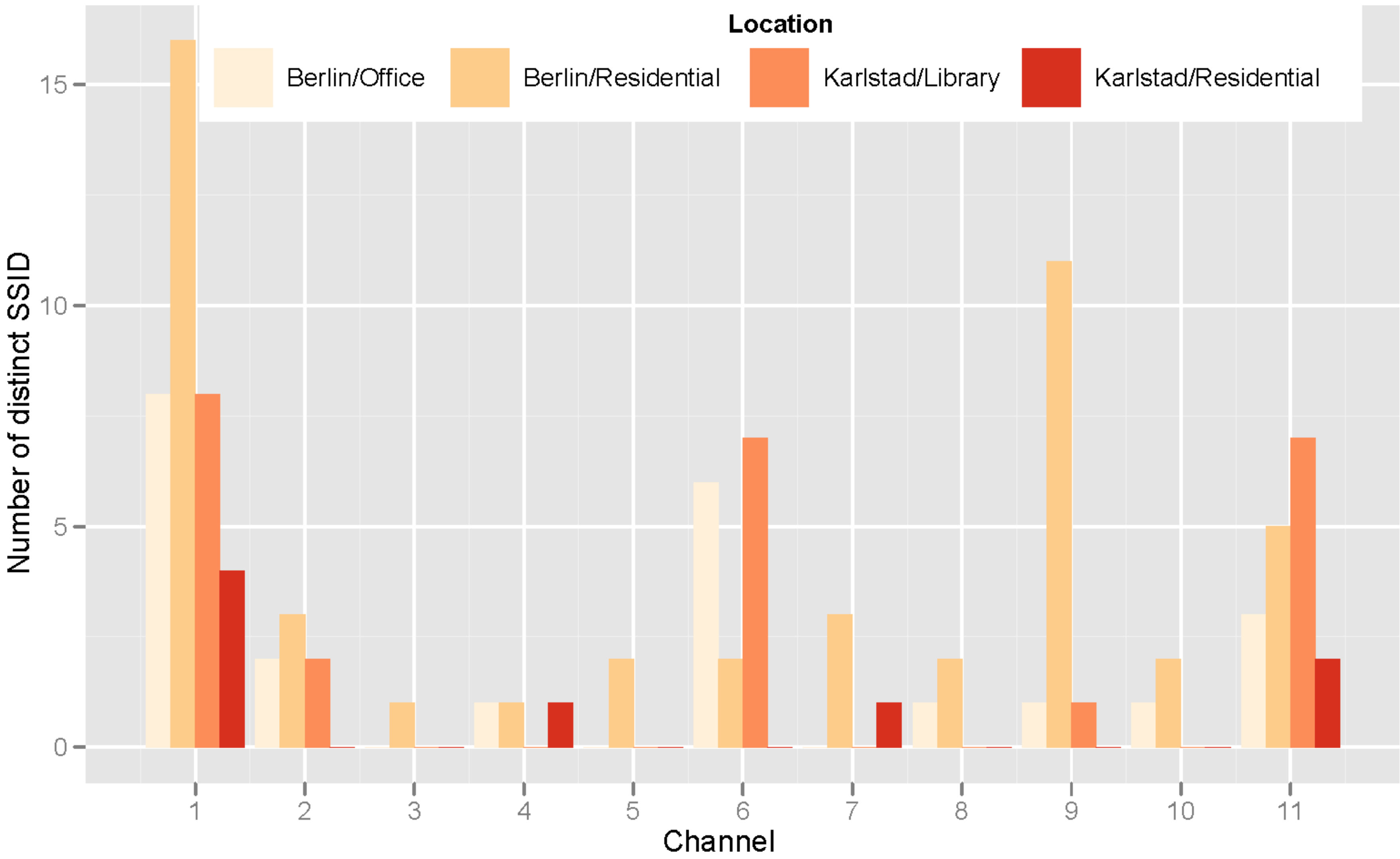
Average hourly channel utilization



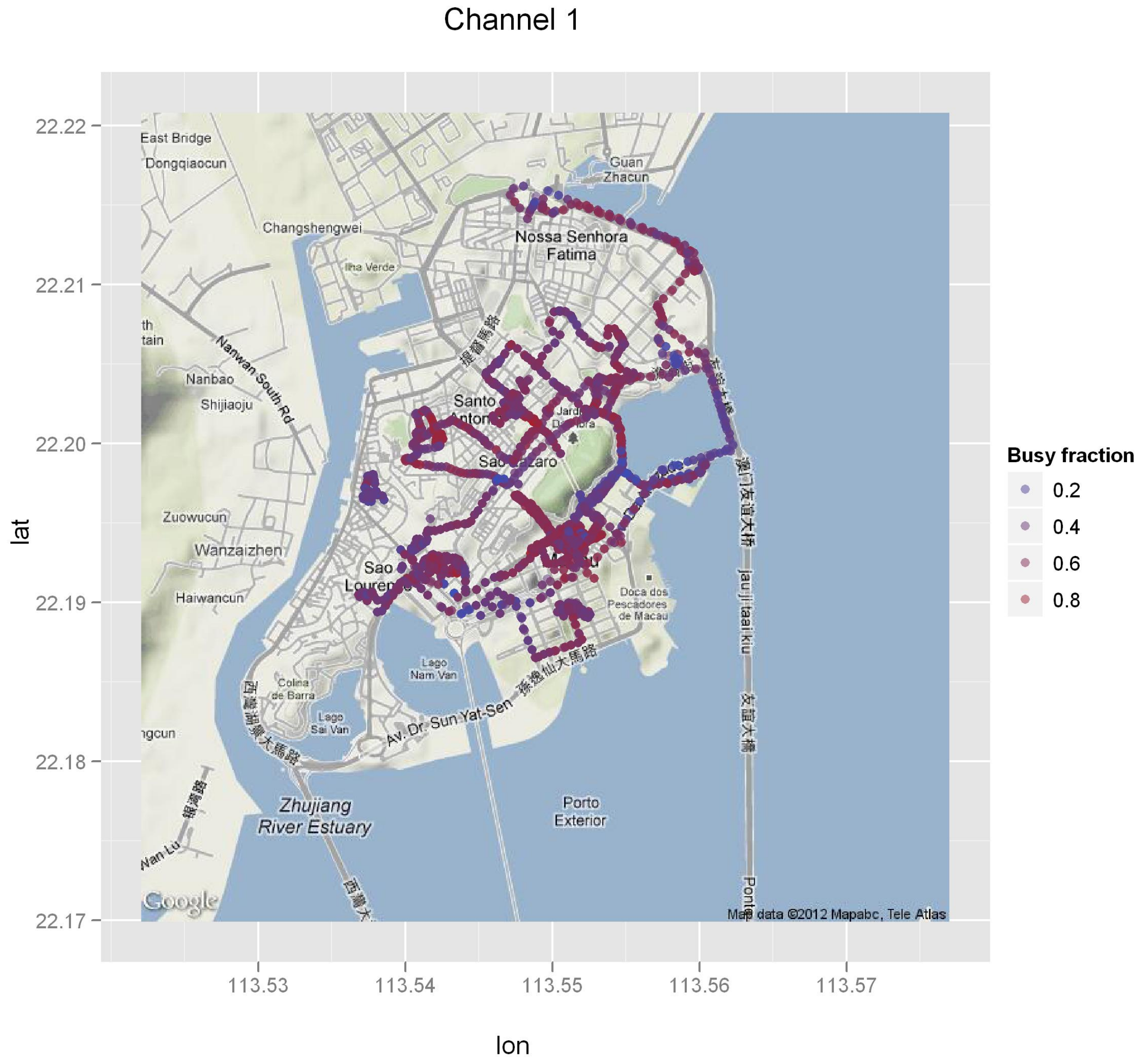
Do best channels stay best and worst channels stay worst?



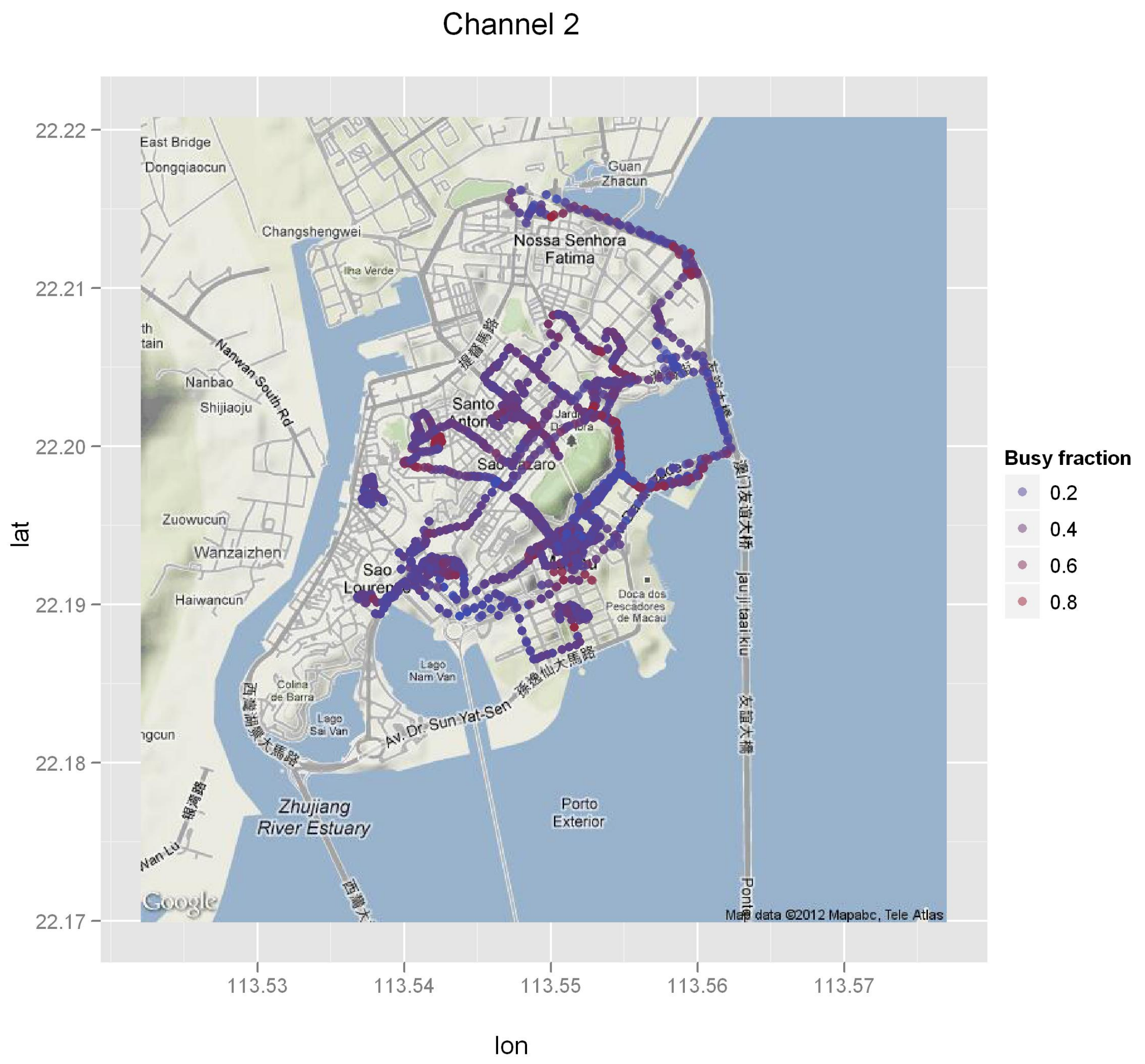
Who creates the channel utilization?



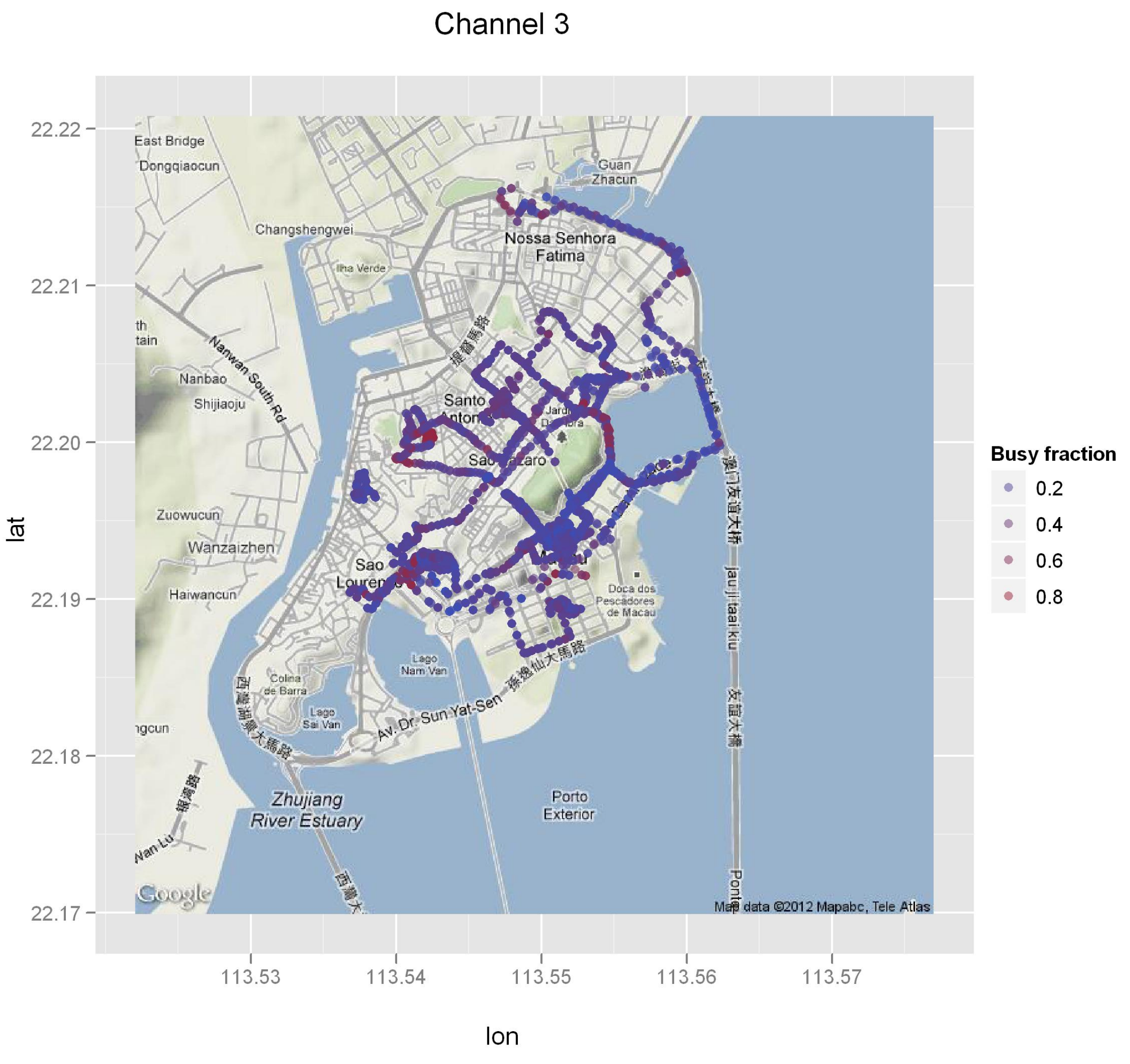
Channel Utilization in Macao



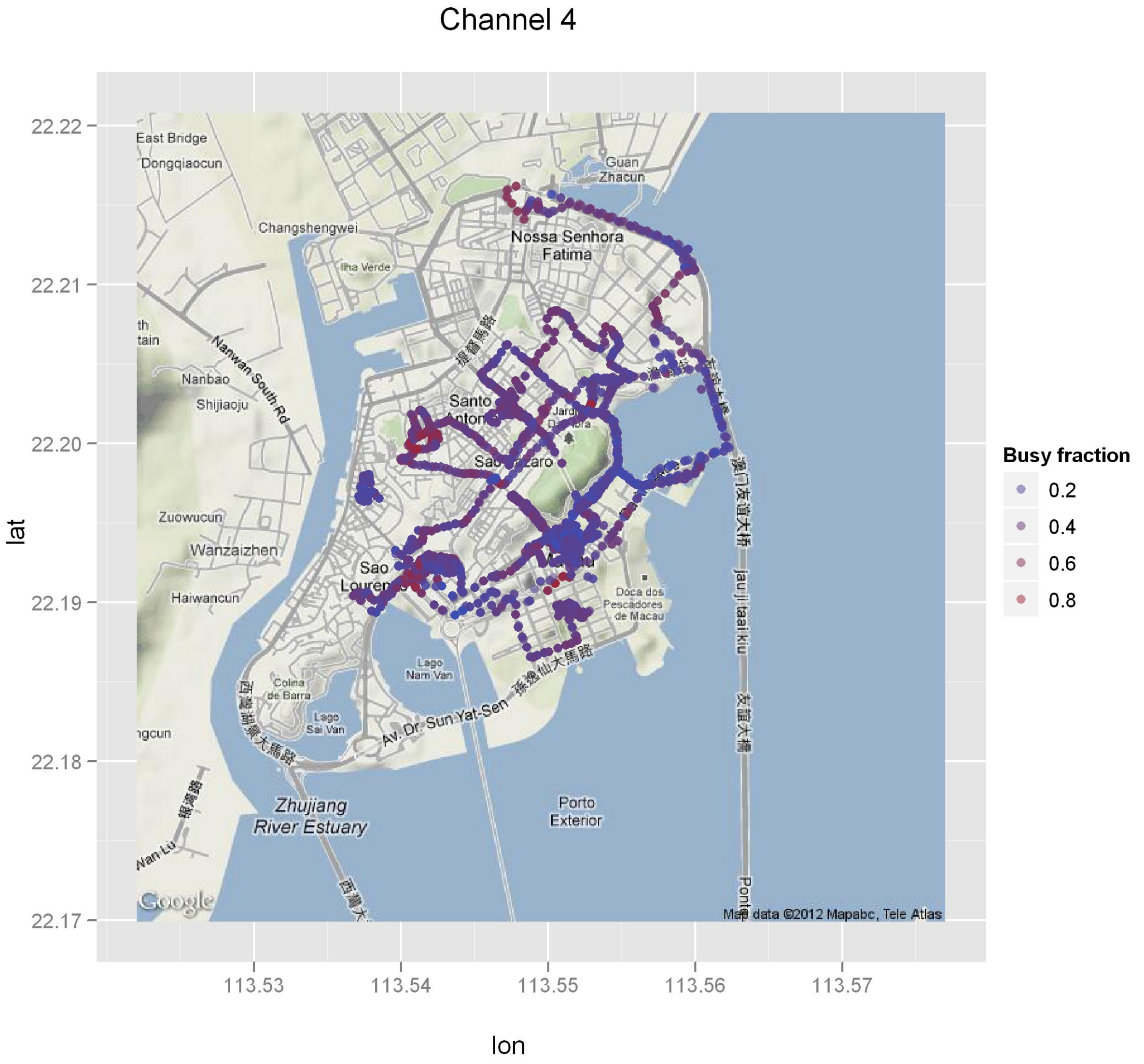
Channel Utilization in Macao



Channel Utilization in Macao

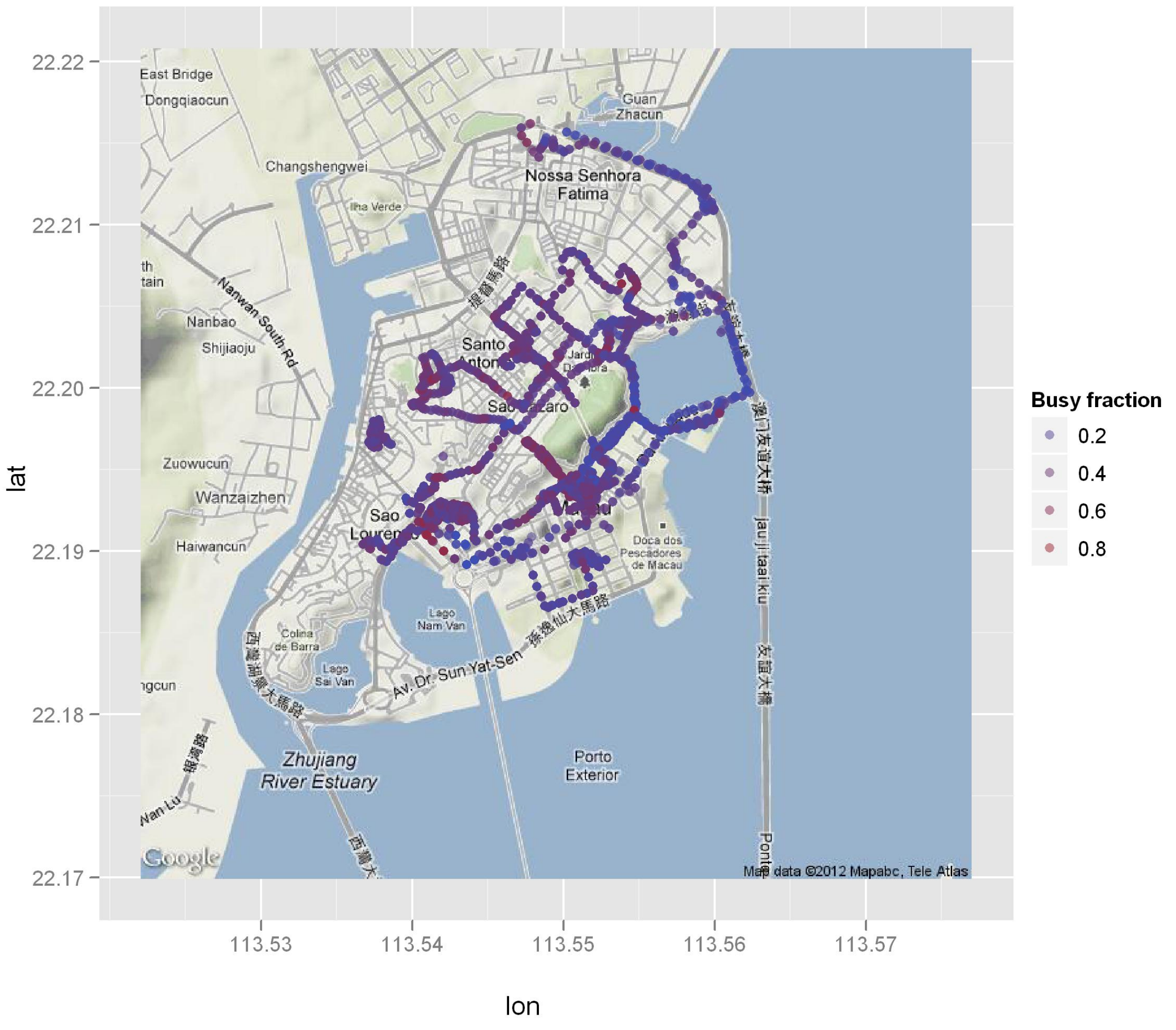


Channel Utilization in Macao

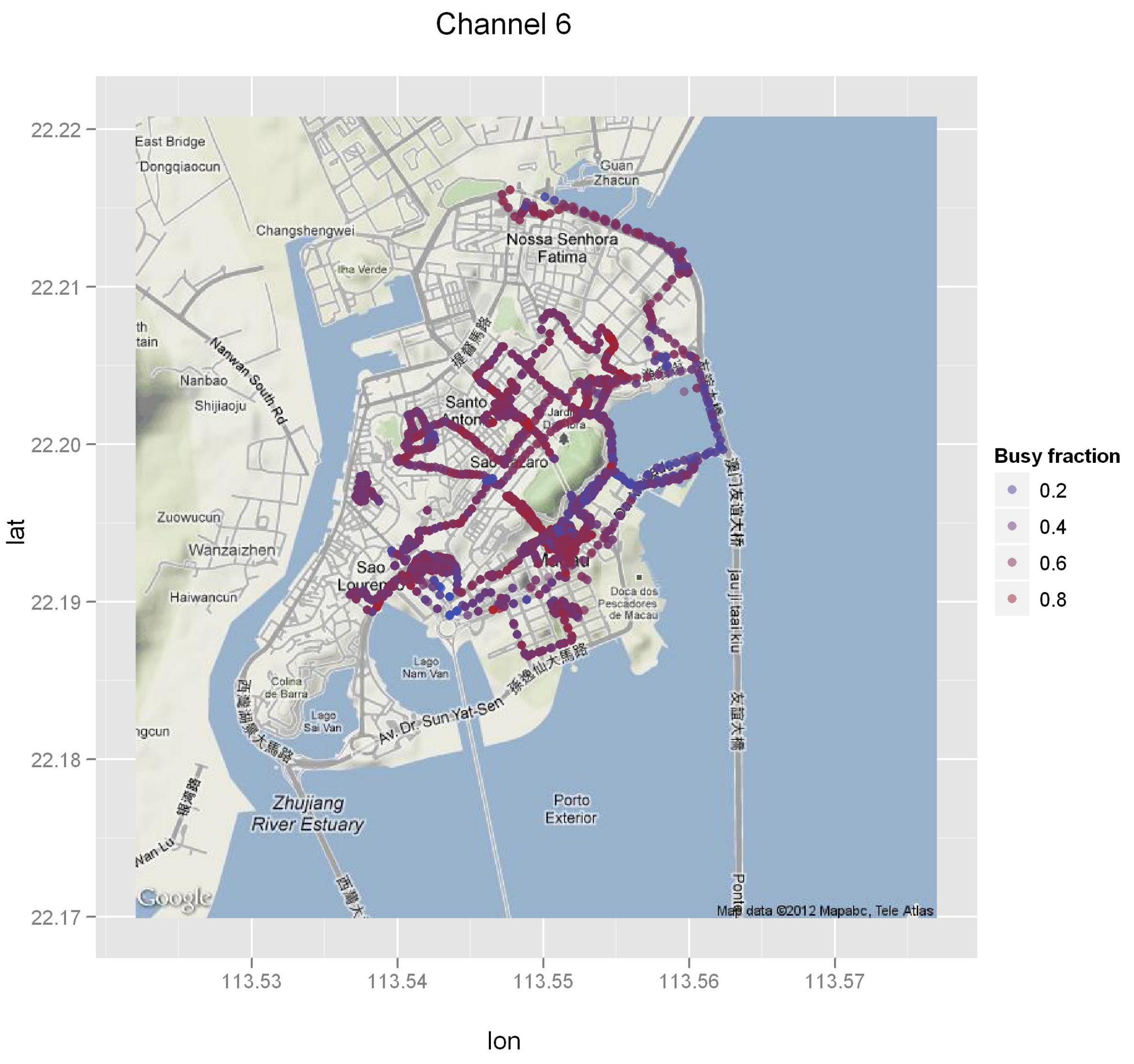


Channel Utilization in Macao

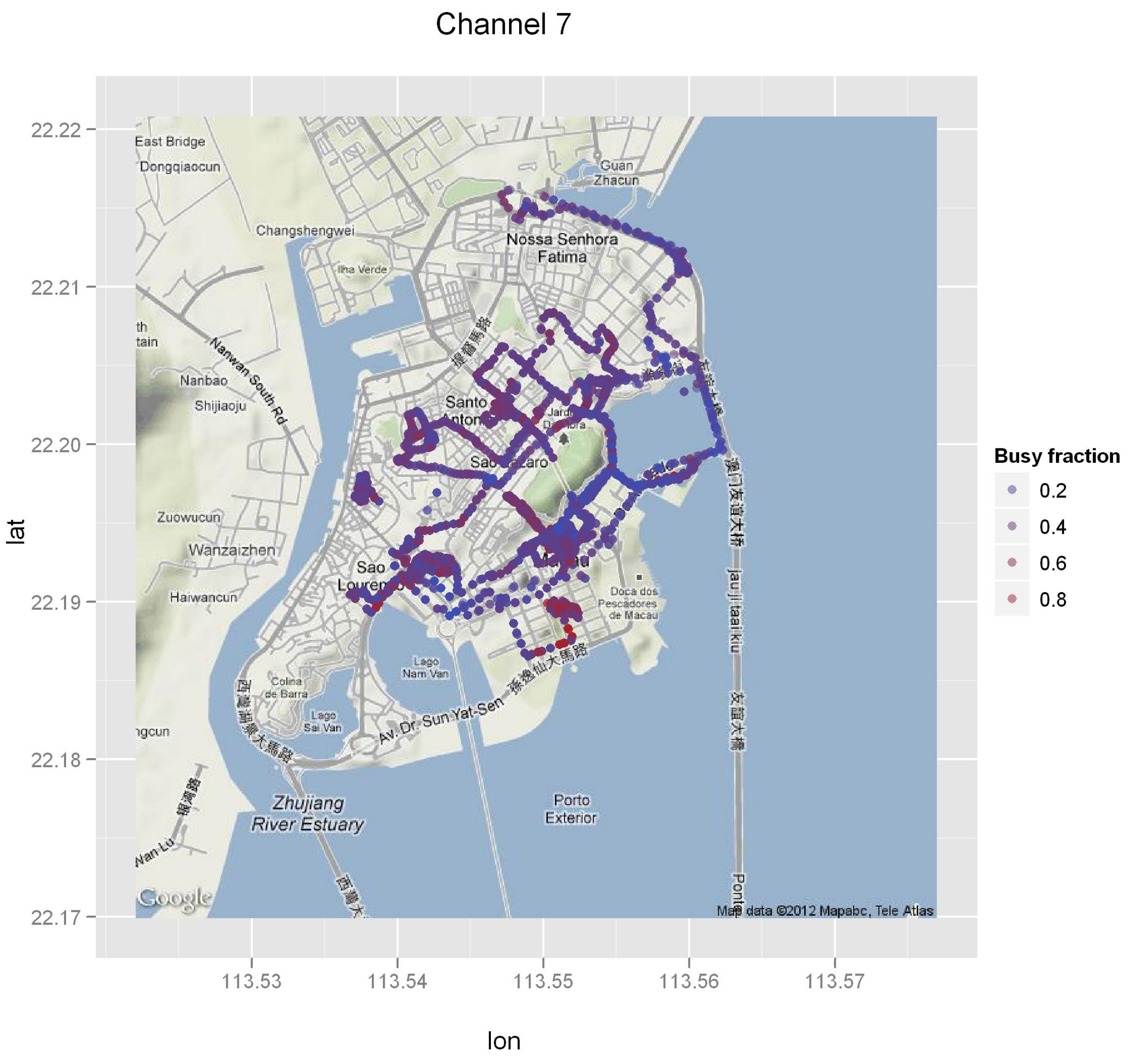
Channel 5



Channel Utilization in Macao



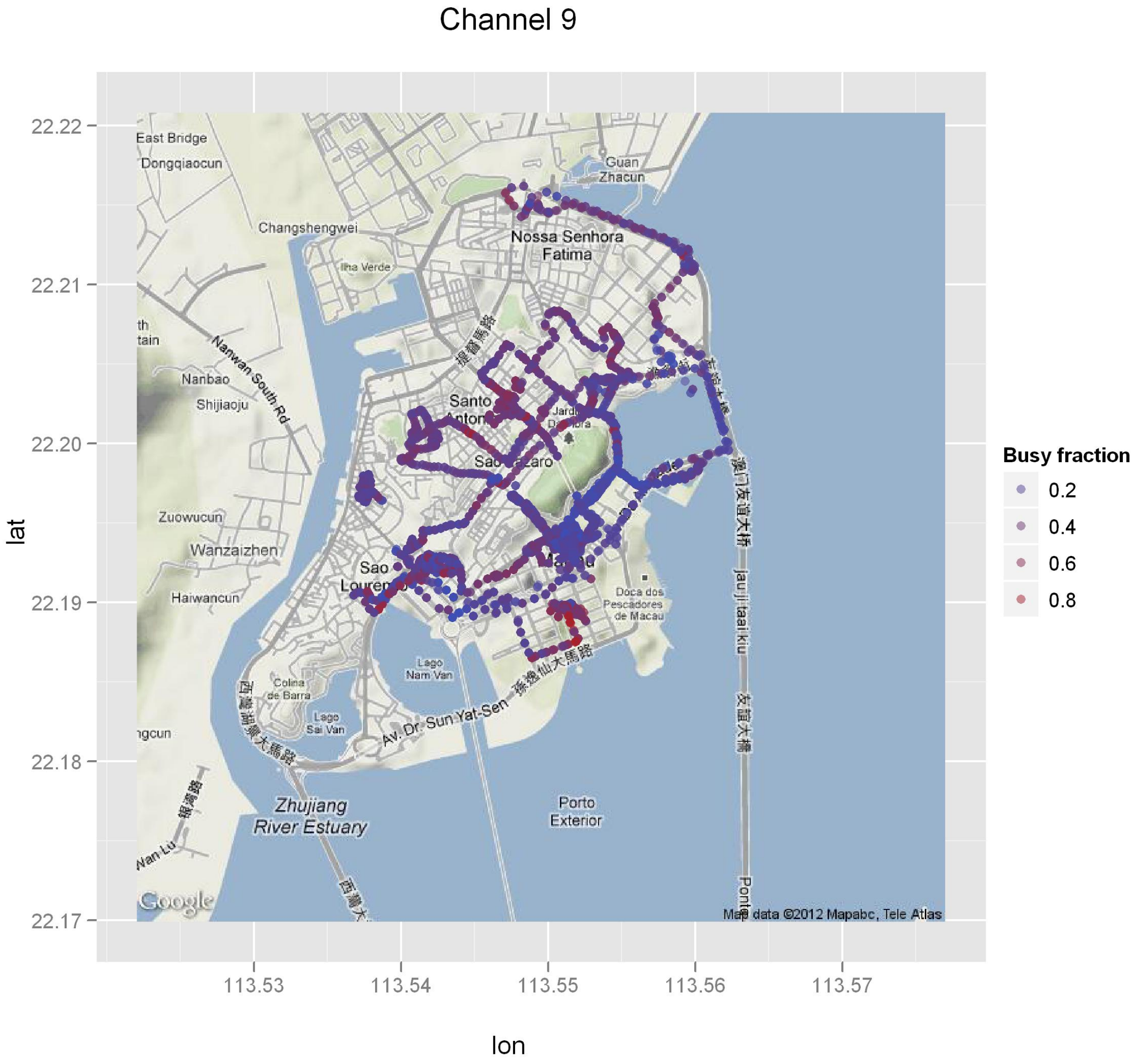
Channel Utilization in Macao



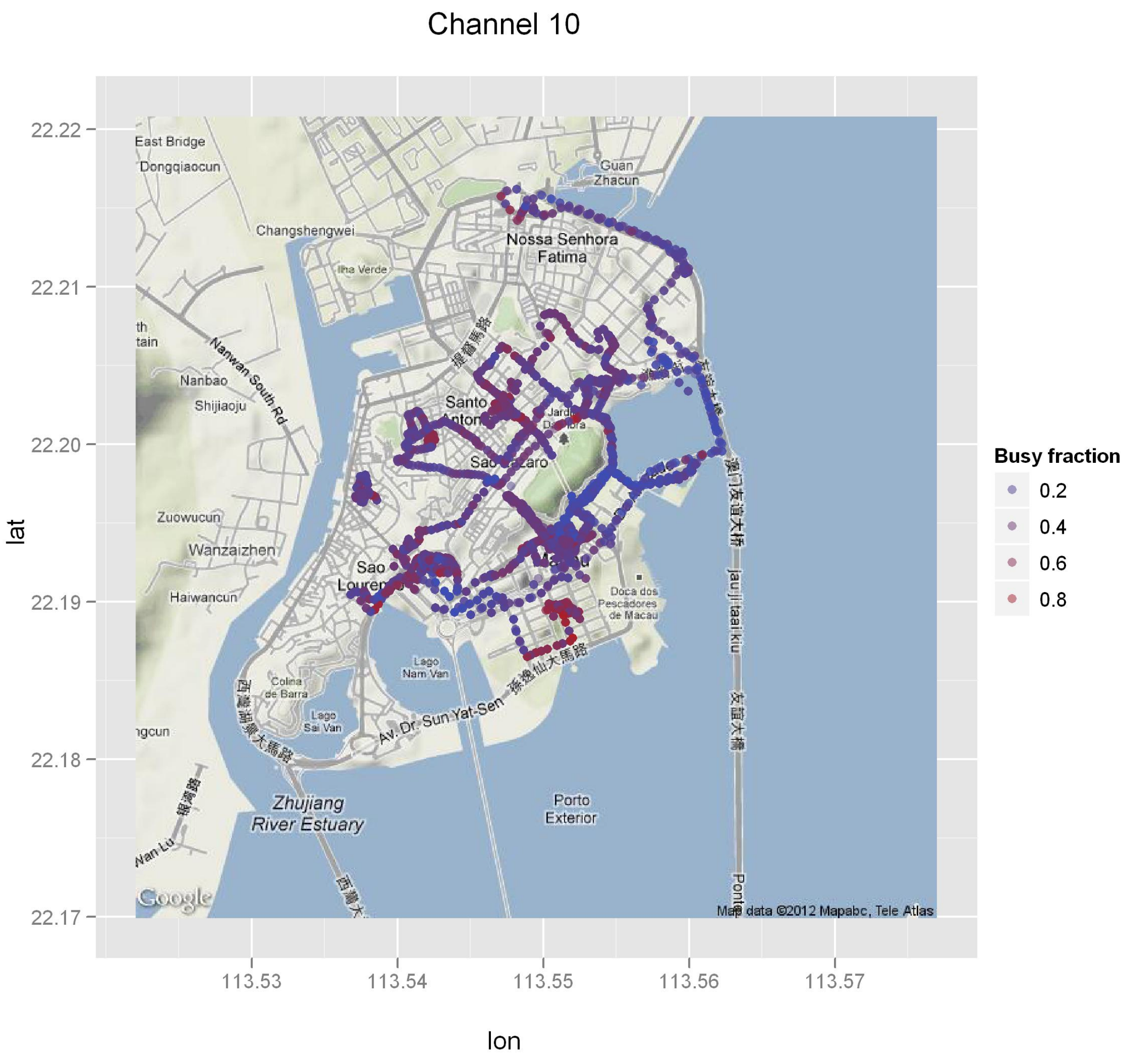
Channel Utilization in Macao

Channel 8

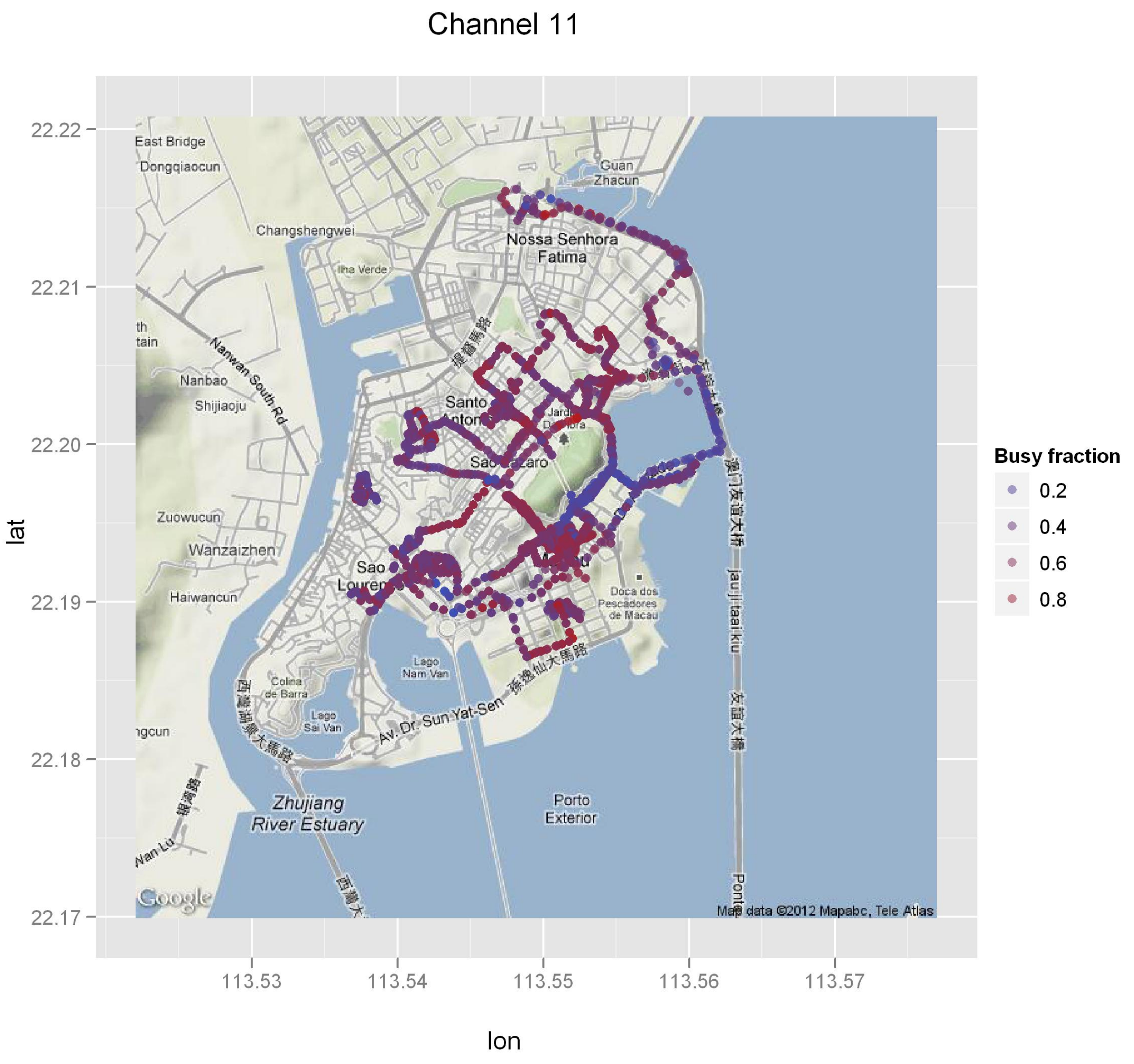
Channel Utilization in Macao



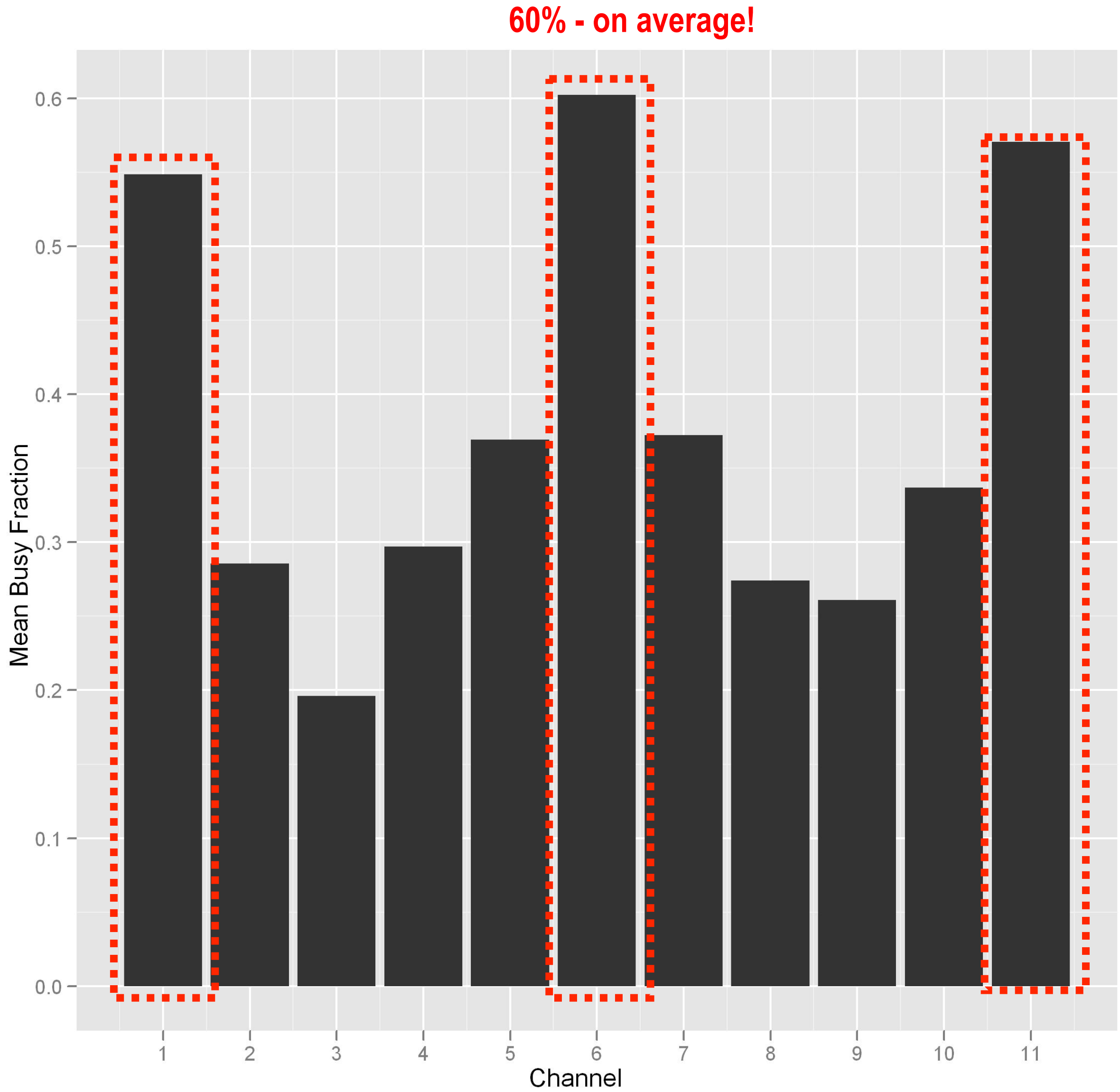
Channel Utilization in Macao



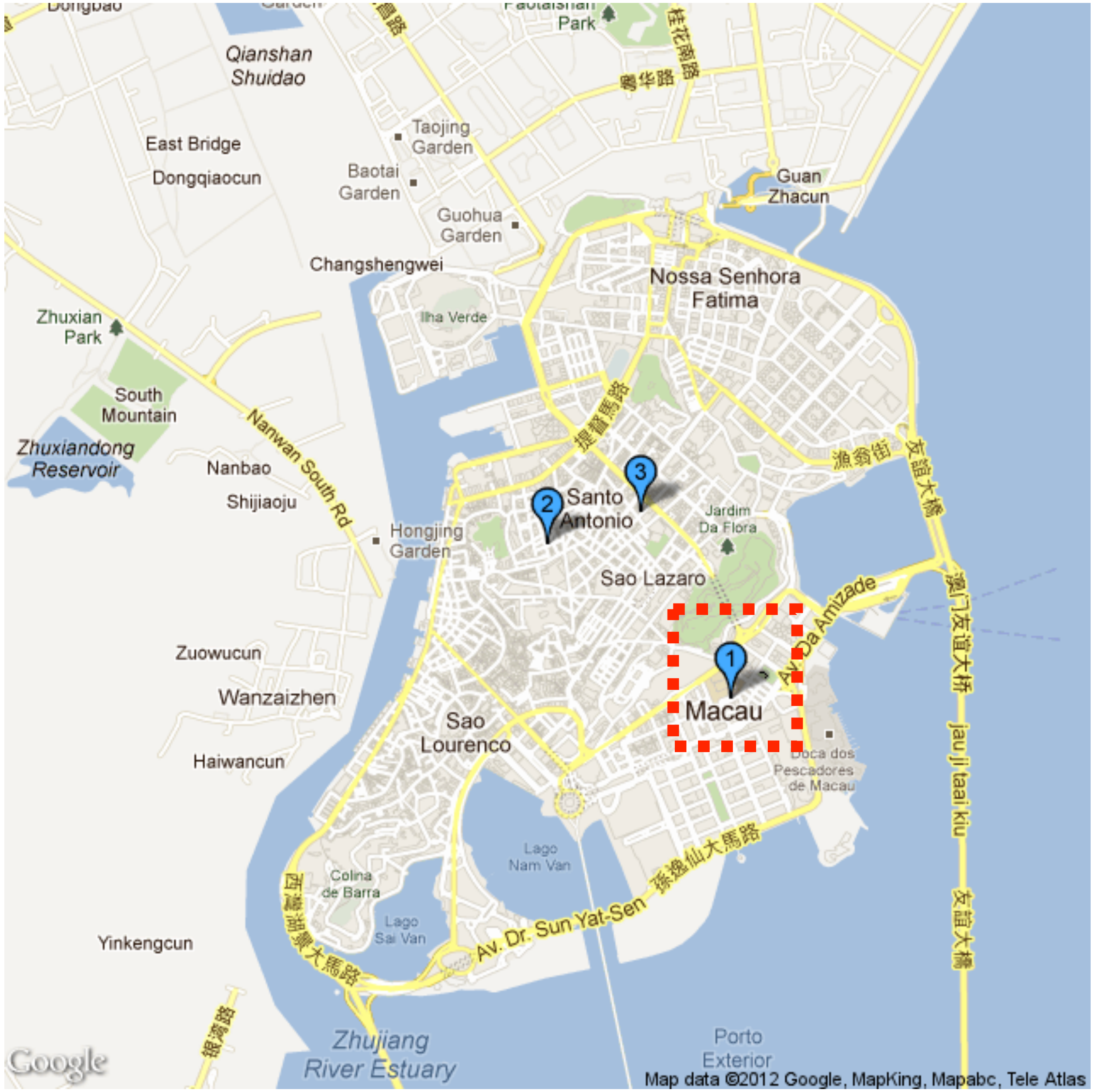
Channel Utilization in Macao



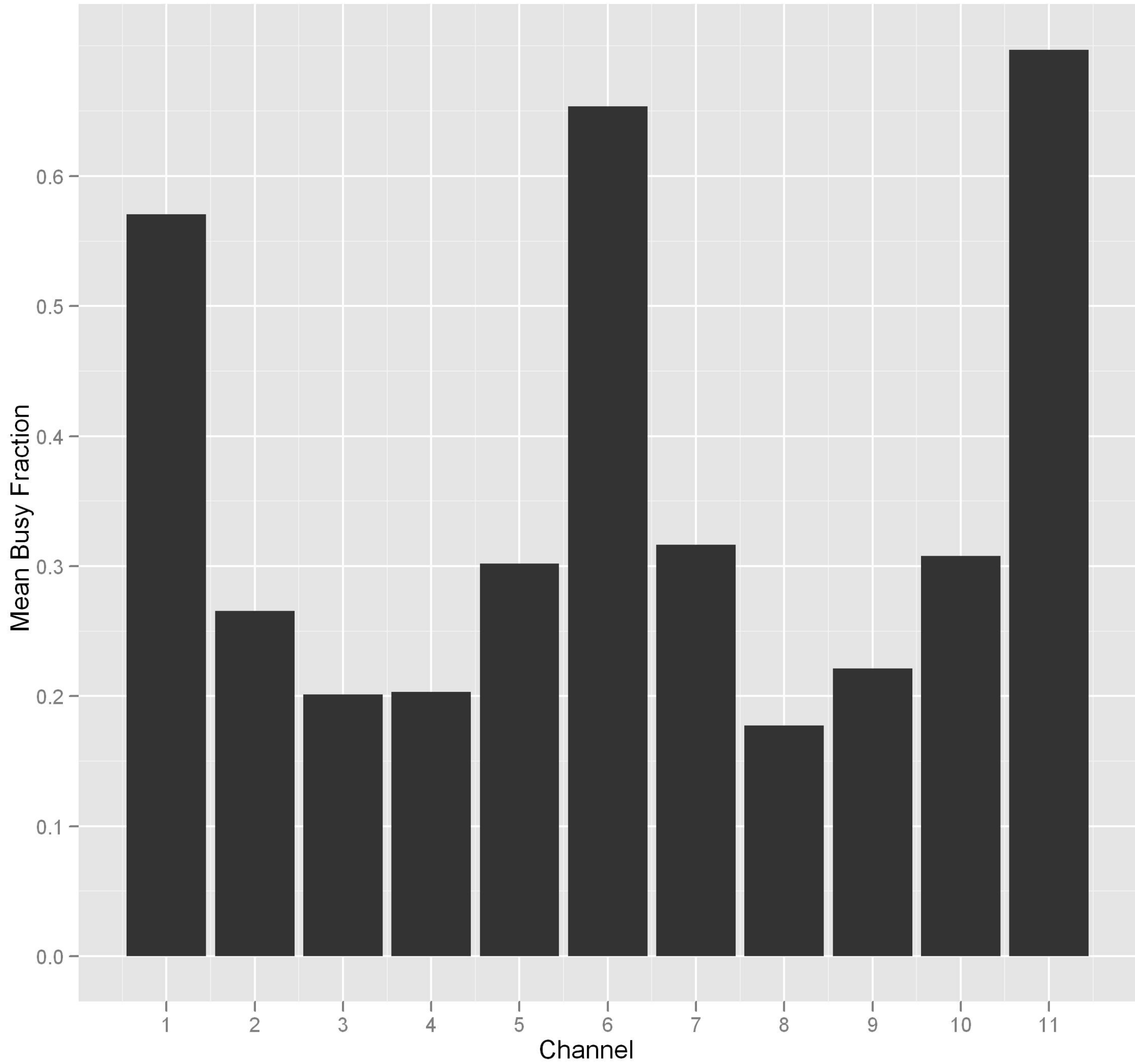
Mean Distribution of Channel Load (all locations)



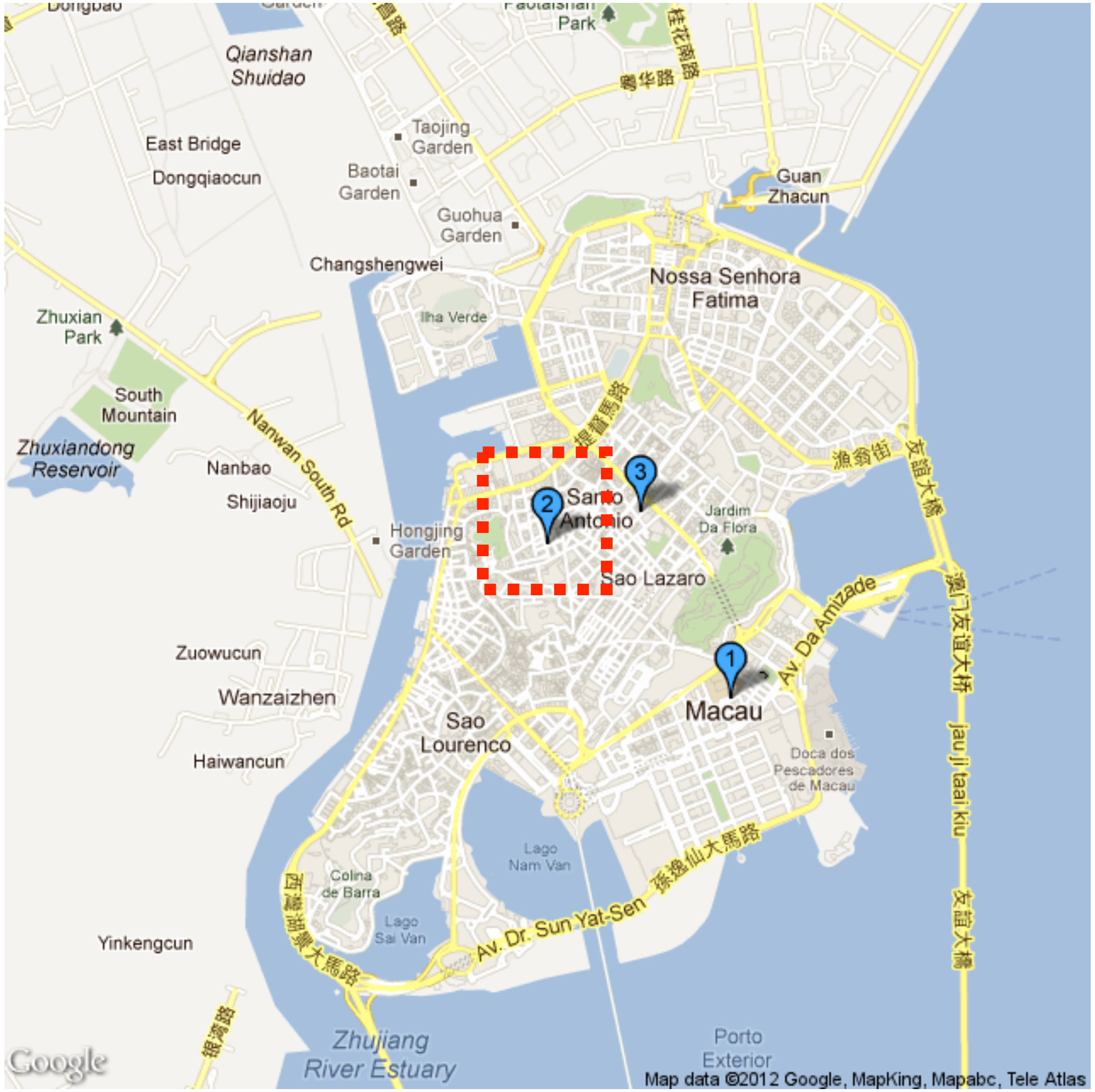
Distribution of Channel Load



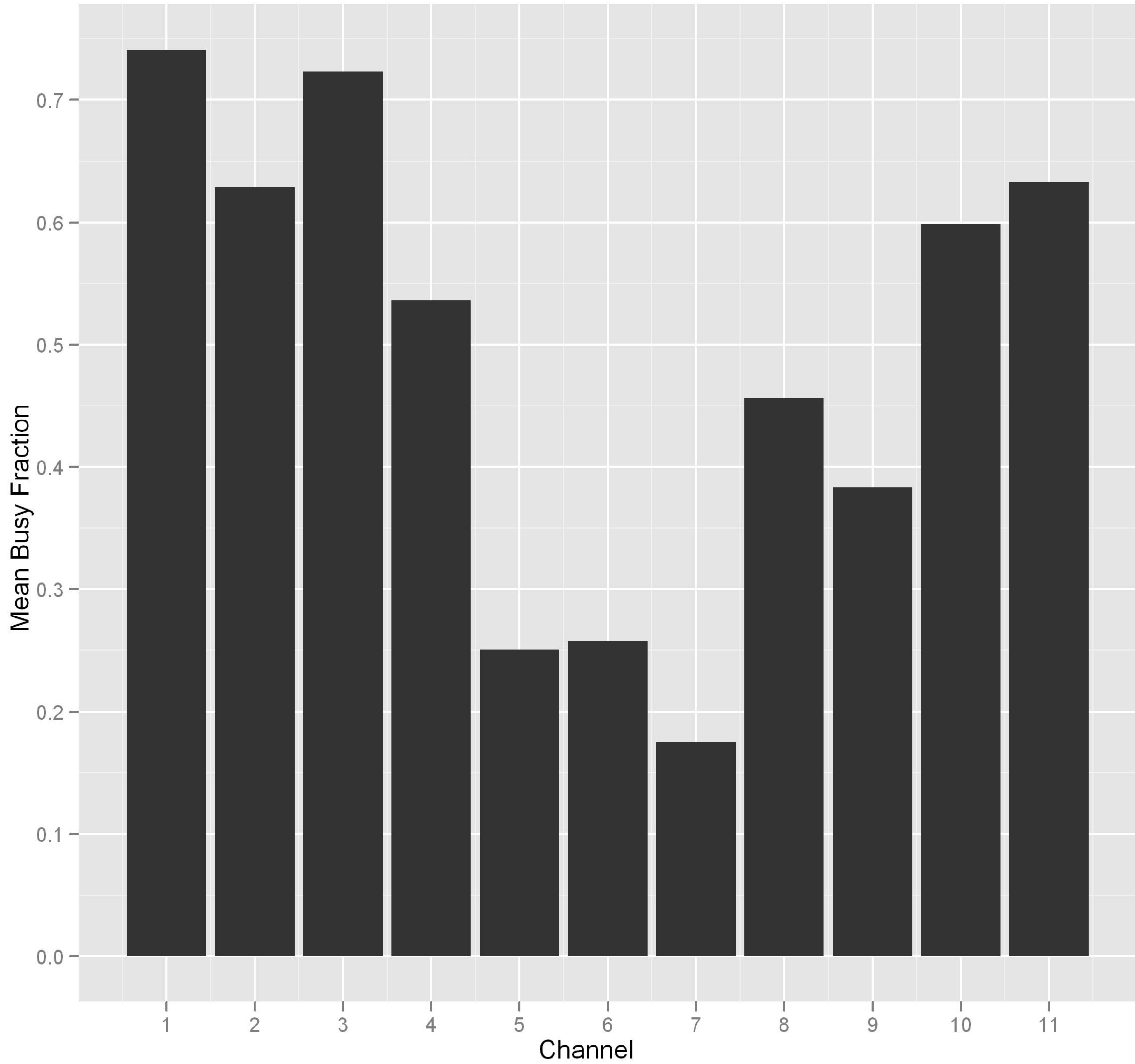
Distribution of Channel Load



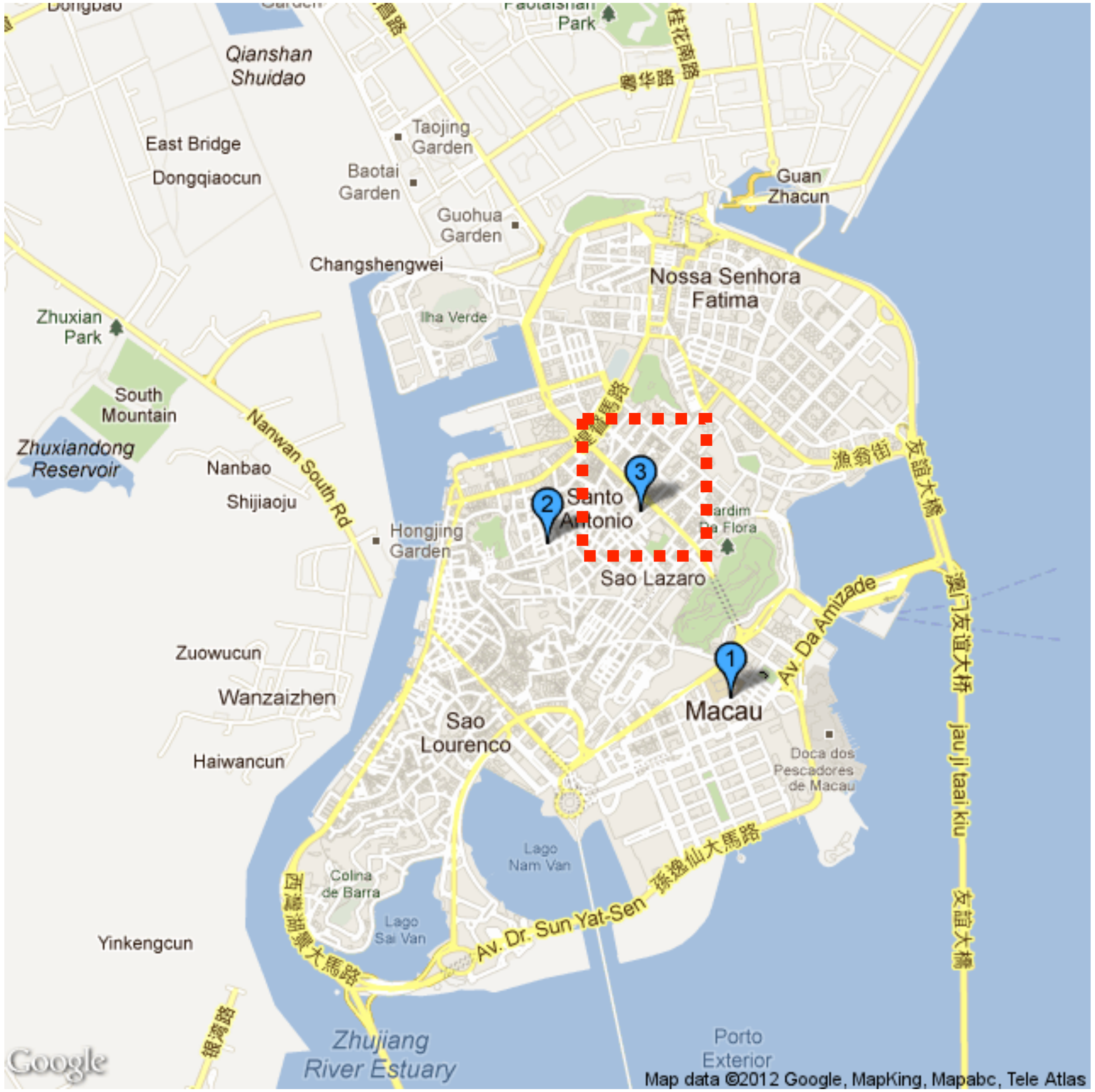
Distribution of Channel Load



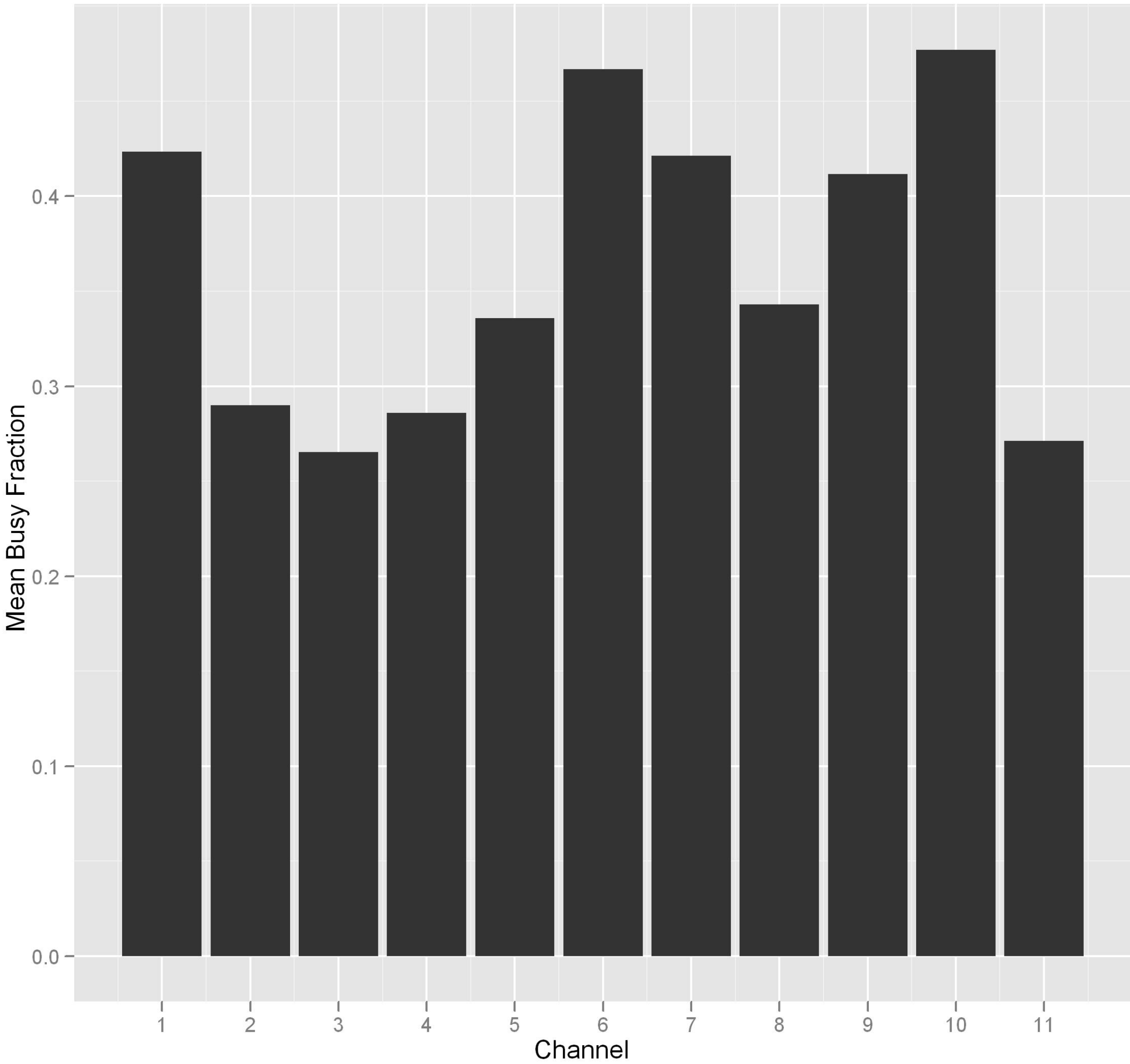
Distribution of Channel Load



Distribution of Channel Load



Distribution of Channel Load



Outline

- WLAN Spectrum Utilisation Measurement
- Urban-X
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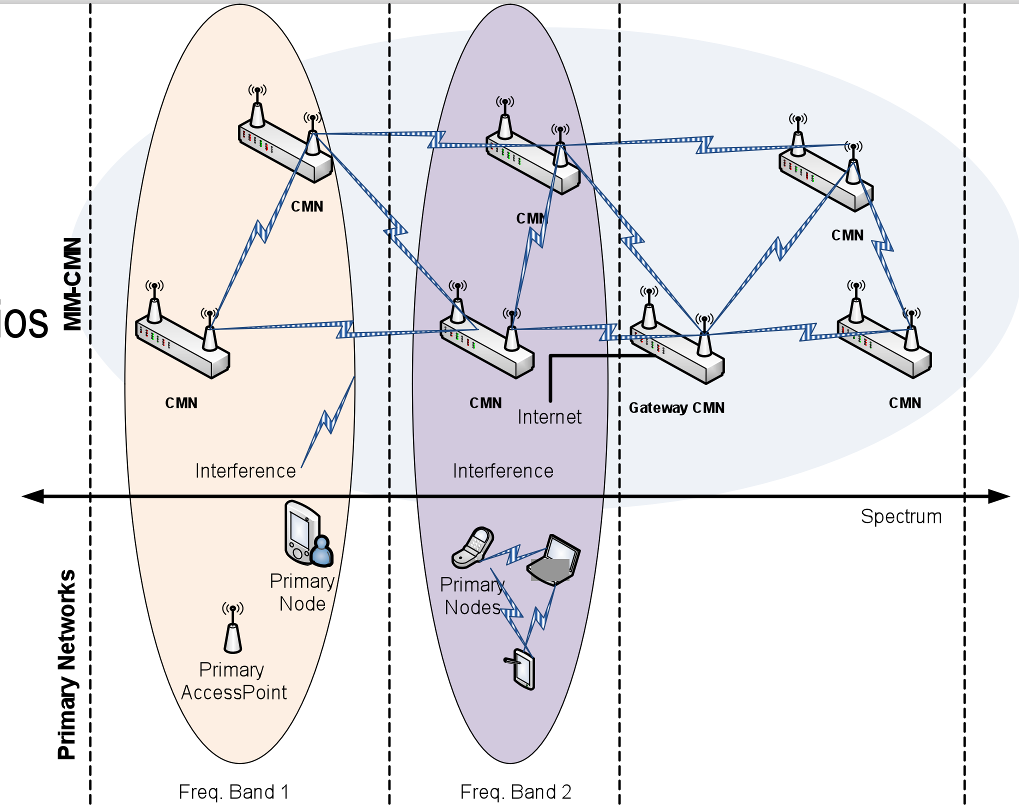
Urban-X System Model

- Cognitive Wireless Mesh Nodes (CMN)
  - Multihop Communication
  - Each node equipped with **m** radios
  - Each radio can transmit/receive over one of **c** channels
  - Multiple radios can be active simultaneously
  - Radios can sense PNs and infer channel utilisation → co-existence

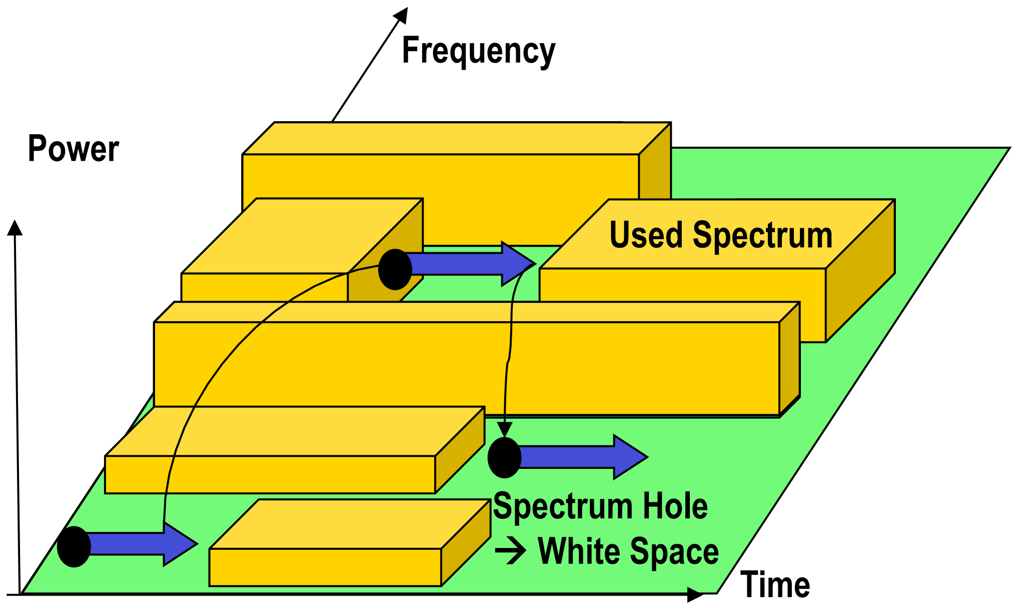


- Traffic management problems:
  - Channel Assignment
  - Routing
  - Scheduling/Forwarding

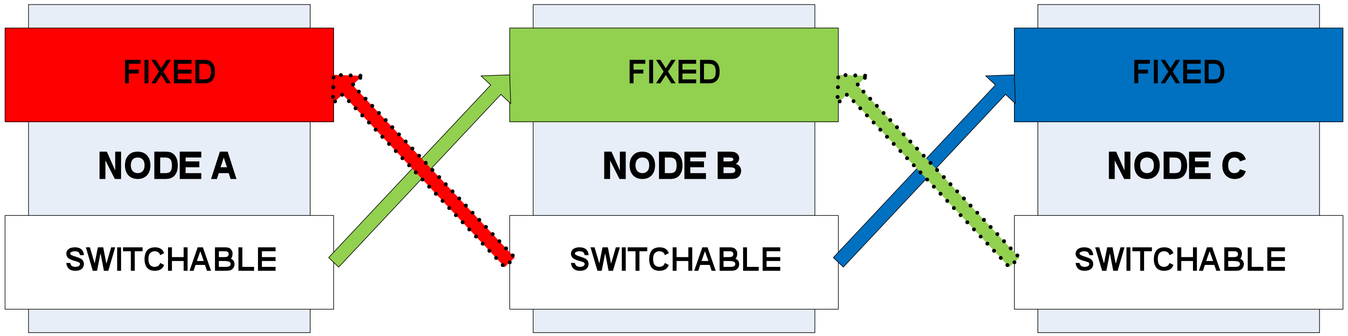
Problems are interdependent

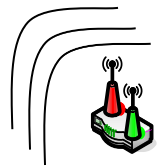
DSA vs. URBAN-X

- Dynamic Spectrum Access (DSA) vs. Urban-X
  - DSA: exploit temporarily unused spectrum portions → Spectrum Holes or White Spaces → TV-bands as example (IEEE802.22)
  - Nodes change transmission parameters on the fly to avoid interference
    - Transmission power, modulation scheme, frequency band, etc
  - In contrast to Cognitive Radio: Our work uses ISM bands→ no need to vacate spectrum immediately but want to find least utilised spectrum portions.



Urban-X Channel Assignment

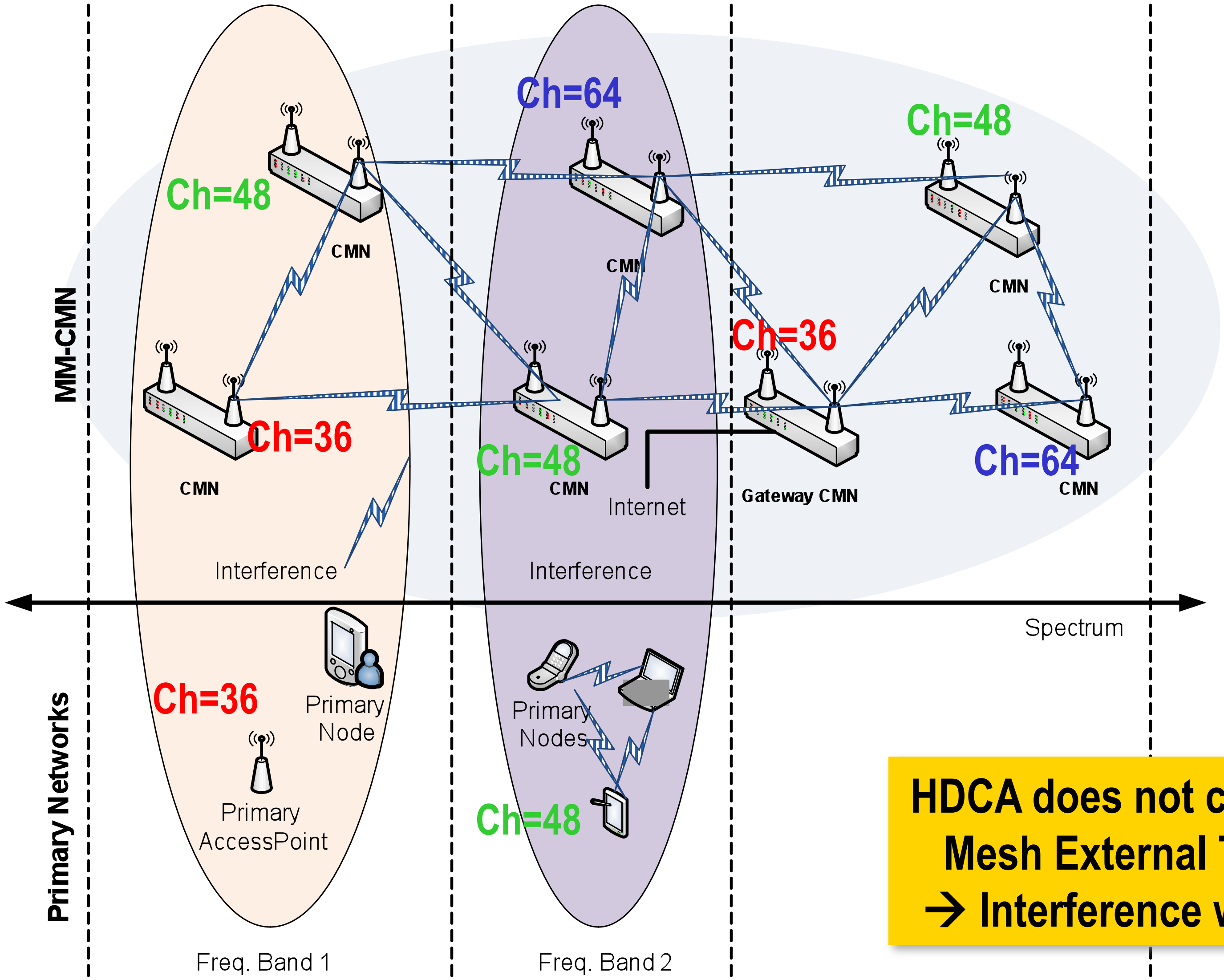




PU, ch=36

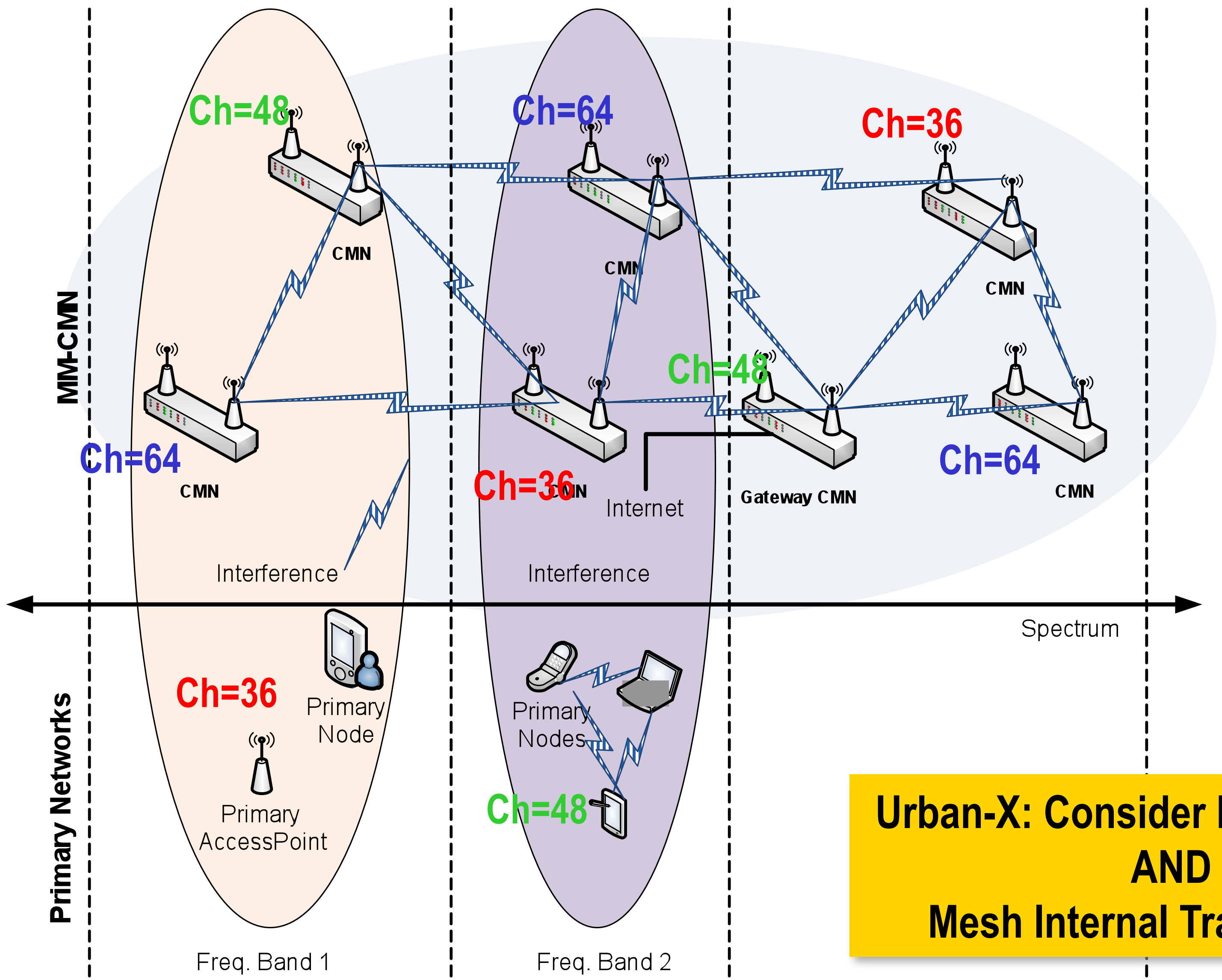
- Hybrid Distributed Channel Assignment (HDCA)
  - Some radios fixed (changes every e.g. 90 s)
  - CA protocol to determine channel for fixed interface (for receiving)
  - Remaining radios can switch dynamically → per channel queing
- Benefits
  - Full connectivity, high throughput, fully adaptable to PN and traffic demand
- Drawback
  - Channel switching delay, add up on multihop routes → TCP performance?
  - Broadcast on all channels requires switching → adopt additional radio on CCC

Problem with HDCA?



HDCA does not consider Mesh External Traffic
→ Interference with PN

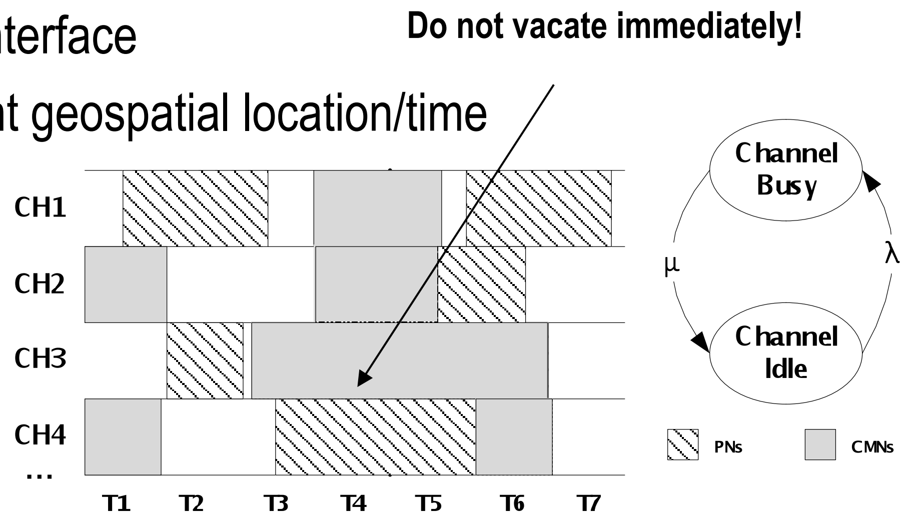
UCA: In Addition consider Mesh EXTERNAL Traffic

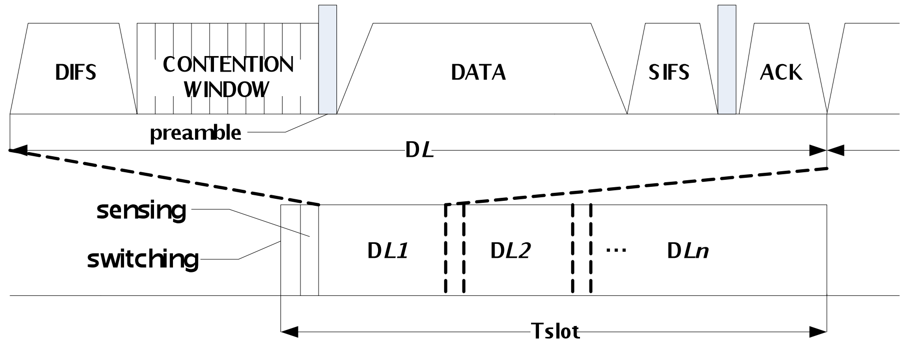


Urban-X: Consider Mesh External AND Mesh Internal Traffic for CA

Spectrum Sensing and Channel Load Estimation

- Goals
  - Determine input for CA for receiving Interface
  - BUT: Channel load different at different geospatial location/time
- Spectrum Sensing
  - Estimate channel workload based on busy/idle estimation
  - Synchronised sensing period
  - Sensing on fixed and switchable radio
  - Tradeoff: large sensing interval
    → good detection probability
    → high overhead
  - CMNs cooperate in exchanging spectrum sensing information within one-hop neighbors
  - Maintain spectrum map for channels where all neighbors are tuned to





Interference Aware Channel Assignment

- Goals
  - Find the channel to be used for Fixed Interface
  - Semi-dynamic: Channel changes according to PN and CMN traffic
  - HDCA: Balance the number of neighbors on a given channel
  - Urban-X: Balance impact due to external AND internal interference
  - Select new channel periodically
- Input
  - Channel workload estimation ω
    → estimate capacity left for CMNs for relaying
  - Adjust capacity according to nr. Neighbors and flows to serve

Algorithm 1 Fixed channel allocation under primary traffic

for each channel i in K **do**
  $C_i = C_{n_0} \cdot (1 - \omega)$, $C_i = C_i / N(i)$
  $C_{CPF,i} = C_i / N(Flows)$
  Q1 ← $C_{CPF,i}$
end for
C_{LCPF} ← EXTRACT-MIN(Q1)
i_{R1} ← EXTRACT-MAX(Q1)

C_{min} ← MIN(Q2), C_{max} ← MAX(Q2)
$C_{CR} = C_{max} - C_{min}$
$prob = 1 - C_{LCPF} / C_{CR}$
if $prob \geq Random[0, 1]$ **then**
  Select i_{R1} as a fixed channel, i_{Rx}
end if

Broadcast HELLO with C_{LCPF} and i_{Rx}
Q2 ← C_{LCPF} received from neighbor nodes
Update $N(i_{Rx})$

$$\omega = \frac{T_{busy}}{T_{busy} + T_{idle}}$$

Interference Aware Channel Assignment

- Idea
  - node gets priority in selecting a given channel if it serves many flows and/or is suffering heavy external interference.
  - Select maximum capacity channel iR1 for receiving interface with a certain probability to balance the channel load among channels and minimize intra and inter flow interference
- Update Neighbors
  - Broadcast selected fixed channel and LCPF on CCC
  - Neighbors update channel map

Algorithm 1 Fixed channel allocation under primary traffic

for each channel i in K **do**
  $C_i = C_{n_0} \cdot (1 - \omega)$, $C_i = C_i / N(i)$
  $C_{CPF,i} = C_i / N(Flows)$
  Q1 $\leftarrow C_{CPF,i}$
end for
$C_{LCPF} \leftarrow$ EXTRACT-MIN(Q1)
$i_{R1} \leftarrow$ EXTRACT-MAX(Q1)

$C_{min} \leftarrow$ MIN(Q2), $C_{max} \leftarrow$ MAX(Q2)
$C_{CR} = C_{max} - C_{min}$
$prob = 1 - C_{LCPF} / C_{CR}$
if $prob \geq Random[0, 1]$ **then**
  Select i_{R1} as a fixed channel, i_{Rx}
end if

Broadcast HELLO with C_{LCPF} and i_{Rx}
Q2 $\leftarrow C_{LCPF}$ received from neighbor nodes
Update $N(i_{Rx})$

N(i): number of nodes selecting channel *i* within two hop neighborhoods
Cn0: max. channel capacity
w: channel workload estimation from spectrum sensing
CLCPF: least capacity per flow

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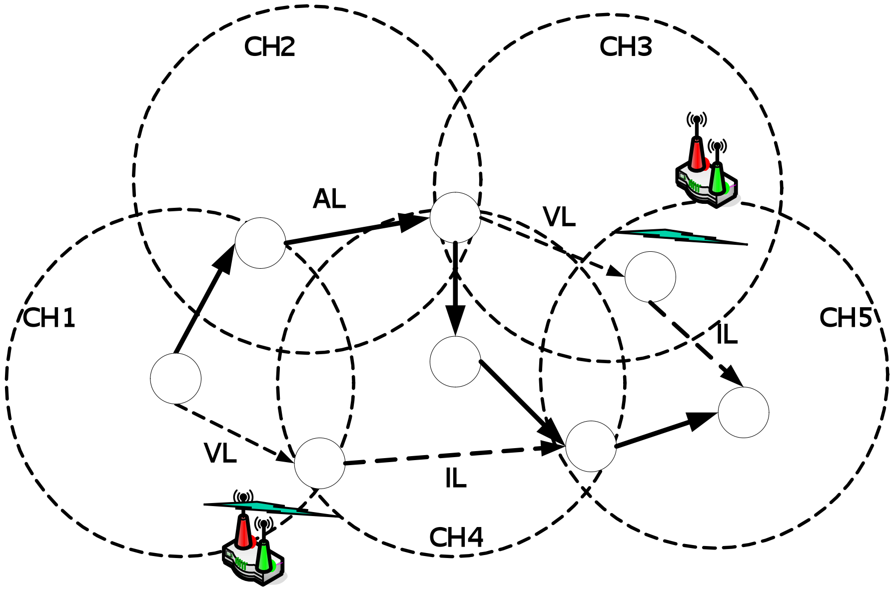
Routing in Cognitive Mesh Networks

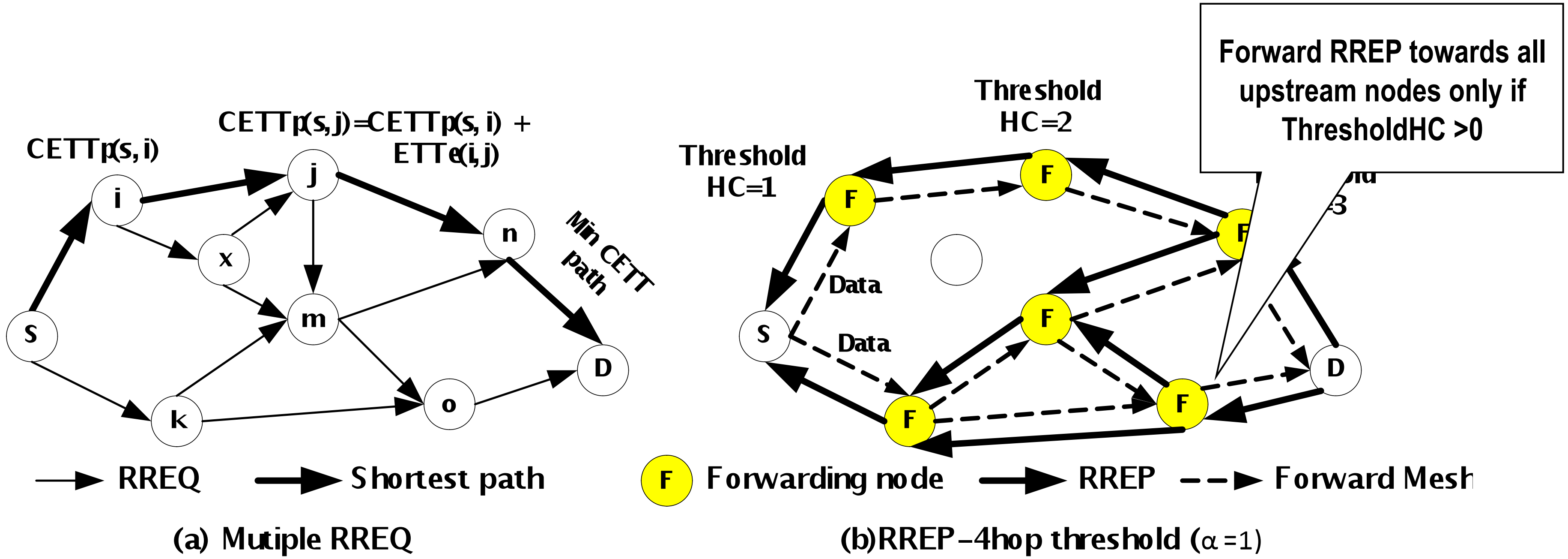
- Approaches:
  - Single path versus multiple
  - Proactive, reactive, hybrid
- Problems:
  - Once path selected, remains active until broken
  - Path may become suboptimal over time
  - Varying residential PN traffic intensity



- Idea:
  - Use multipath for loadbalancing and cope with varying PN interference
  - Create forwarding mesh of candidate forwarders, on different channels
  - Use layer 2.5 forwarding to decide which candidate to use during runtime
  - Integrate with backpressure scheduling for loadbalancing

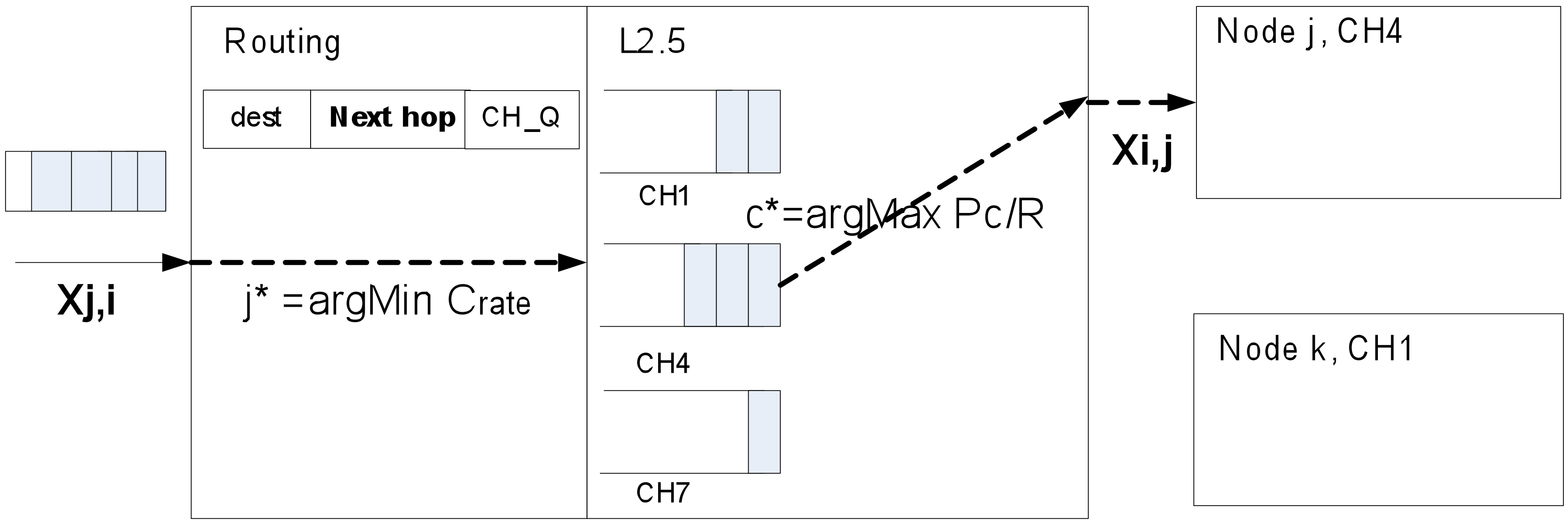
Routing in Urban-X

- Urban-X Multipath routing
  - Active links, virtual links
  - CETT routing metric uses estimates for per link PER based on PN traffic estimation, packet length, SINR and modulation scheme
  - Extended AODV to create forwarding mesh using multiple next hop candidates
    - Changed RREQ and RREP processing to create multiple next hop candidates
    - Threshold for max path length



Layer 2.5 Forwarding in Urban-X

- Forwarding
  - Decide for each packet which channel/next hop
  - Adjust to congestion and external PN traffic
  - Based on multi-channel backpressure
    - Consider switching cost while maximizing network utility function
  - Per channel queue
  - Channel scheduler



Layer 2.5 Forwarding in Urban-X

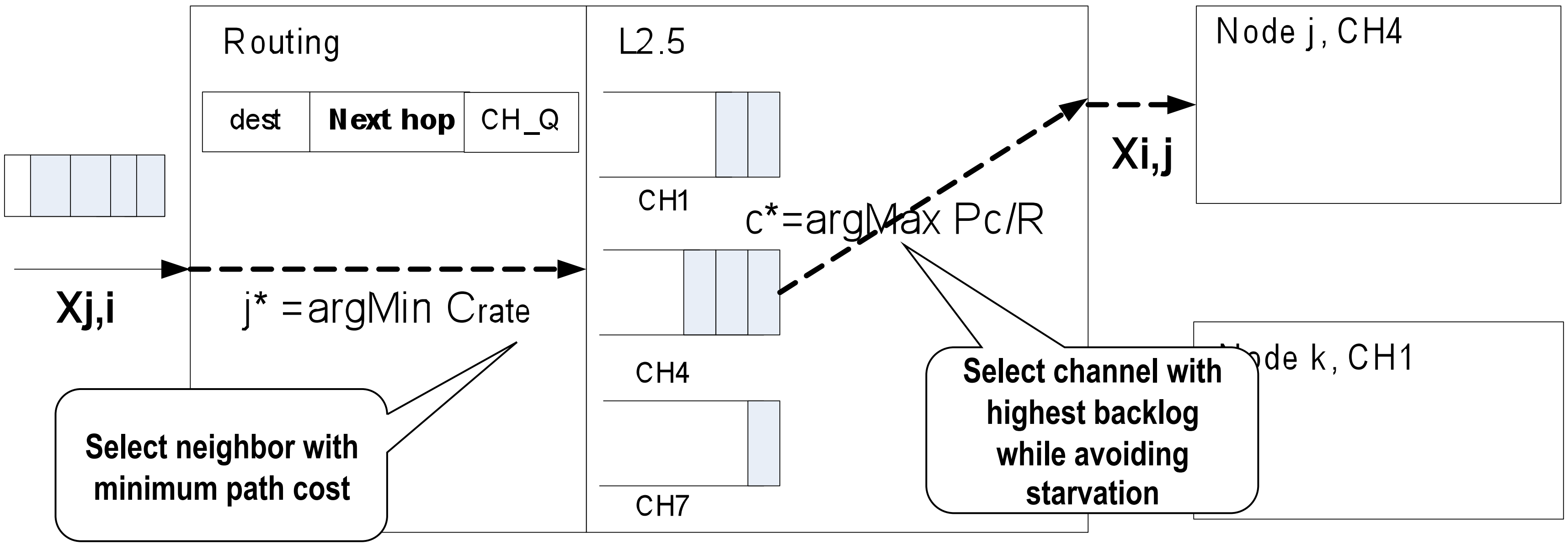
- C… roach
  - Routing … yer 2.5 share Channel Table and Flow Table

Updated every sensing interval

Updated every MAC layer ACK reception, take into account switching delay

Channel	Workload	PER
36	0.4	0.1
64	0.6	0.2

FlowID	NextHop	Chan	ChanCost	PathCost
A→B	C	36	0.8	5
A→E	D	64	0.6	4



Layer 2.5 Forwarding in Urban-X

- Putting it together

Algorithm 2 Packet forwarding algorithm

Step 1.Route resolution for new packets in routing layer
Node i finds multiple next hop candidates j of $flow(src, dest)$ in routing table
$j = rt(dest, nexthop),\ j \in G$
for each neighbor node j **do**
  $Q \leftarrow j(C^f_{rate,j})$,
end for
$j^* \leftarrow$ EXTRACT-MIN(Q)
c $\leftarrow$ NEIGHBOR-CHANNEL-TABLE(j^*)
Enqueue packets to CH-Q(c)
if c=current channel **then**
  $D_{sw} = 0$
else
  D_{sw} = SWITCH-INTERVAL/2
end if
$Z_{ic} = 1/(1/Z_{ic} + D_{sw})$
Update $C^f_{c,i}$

node selects a next hop
j∗ to reach the destination with the lowest cost,
Enque packet into correct channel queue

Consider switching time when best channel not tuned in

Update channel cost for next hop according to estimated PN load

Layer 2.5 Forwarding in Urban-X

- Channel Scheduler

Performed every channel switching interval, e.g. 70 ms

Step 2. Schedule transmission channel switching in layer 2.5

for each channel c of f, $c \in K$ **do**
  $Q \leftarrow \frac{P_c^f}{R_{cj}}$, $P_c^f > 0$, $j \in G(j \neq i)$
end for
$c^* \leftarrow$ EXTRACT-MAX(Q)
while Q $\neq 0$ **do**
  $c \leftarrow$ EXTRACT-MAX(Q)
  if $T_c <$ current time - $T_{minSched}$ **then**
    $c^* \leftarrow$ c, Stop WHILE-loop
  end if
end while
Tune switchable interface to channel c^*, $T_c =$ current time
Dequeue a packet from CH-Q(c) of flow f and transmit it,
Update $C_{rate,j}^f$

Select channel queue which has highest workload

Avoid starvation of other queues

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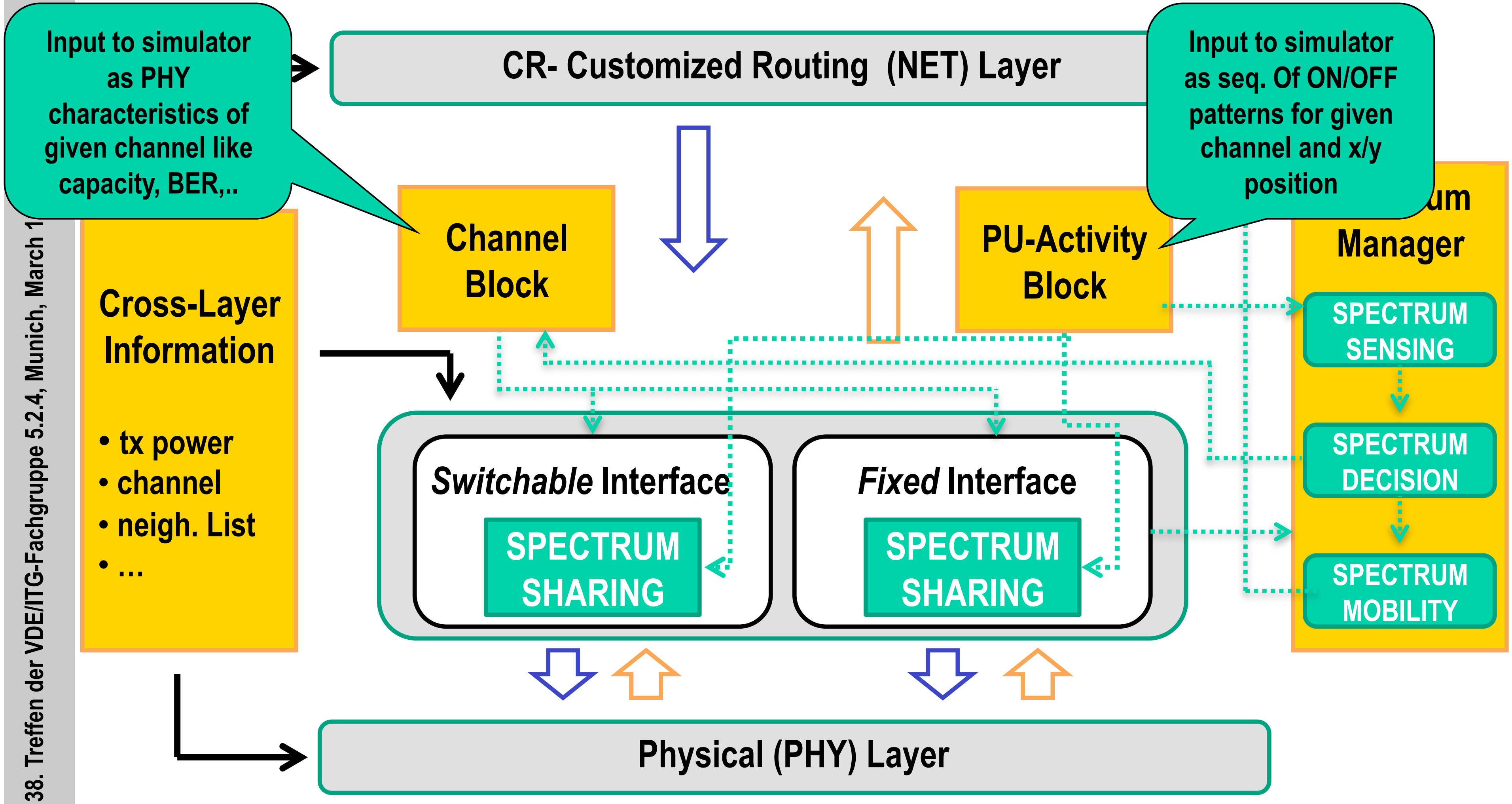
CMN Simulator Architecture

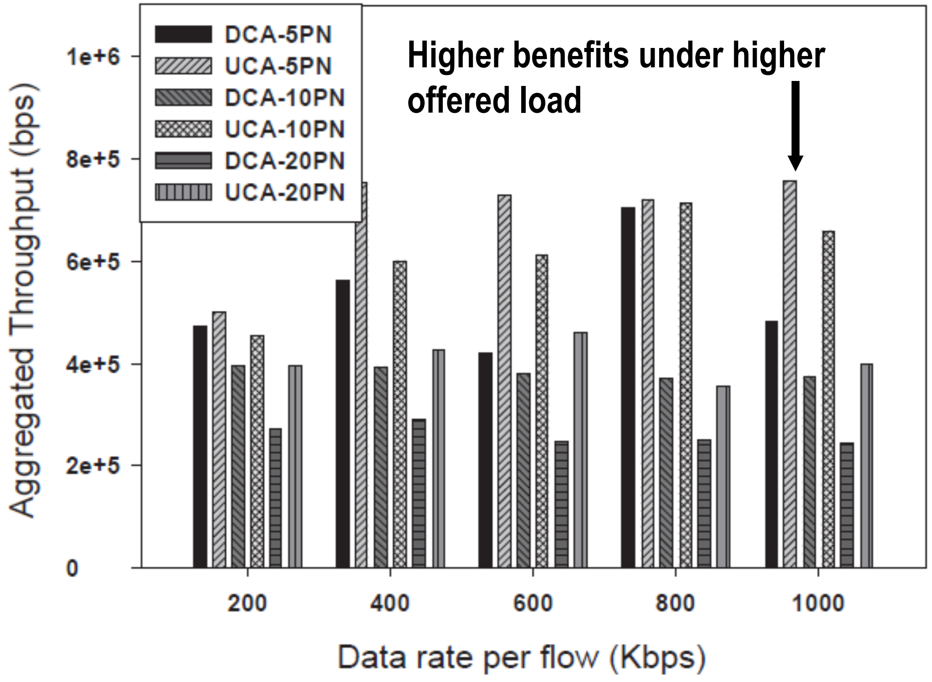


Marco Di Felice, Kaushik Roy Chowdhury, Luciano Bononi, Andreas Kassler: *End-to-end Protocols for Cognitive Radio Ad Hoc Networks: An Evaluation Study*. To Appear in: Elsevier Journal of Performance Evaluation.

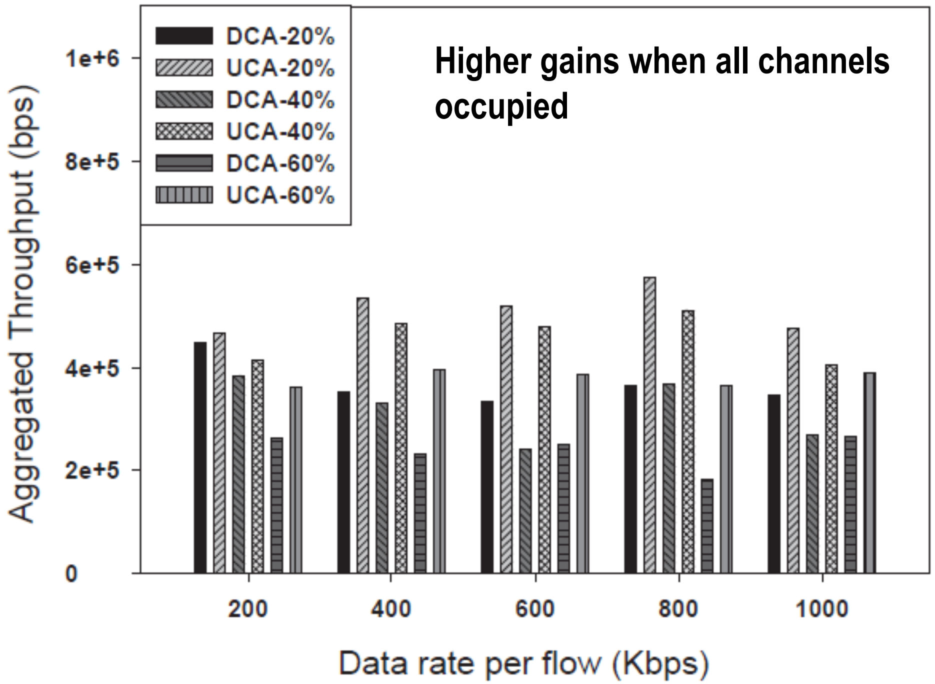
Performance Evaluation – Random Topology

Ns-2 with CRAHN extension [DiFelice09]
- 2 Mbps fixed data rate
- 10 channels in total, 1 channel designated for CCC
- Sensing period for channel workload measurement: 70 msec/s
- 50 nodes, randomly placed
- Varying number of PNs
- 3 CBR flows

UCA selects channels having lowest interference



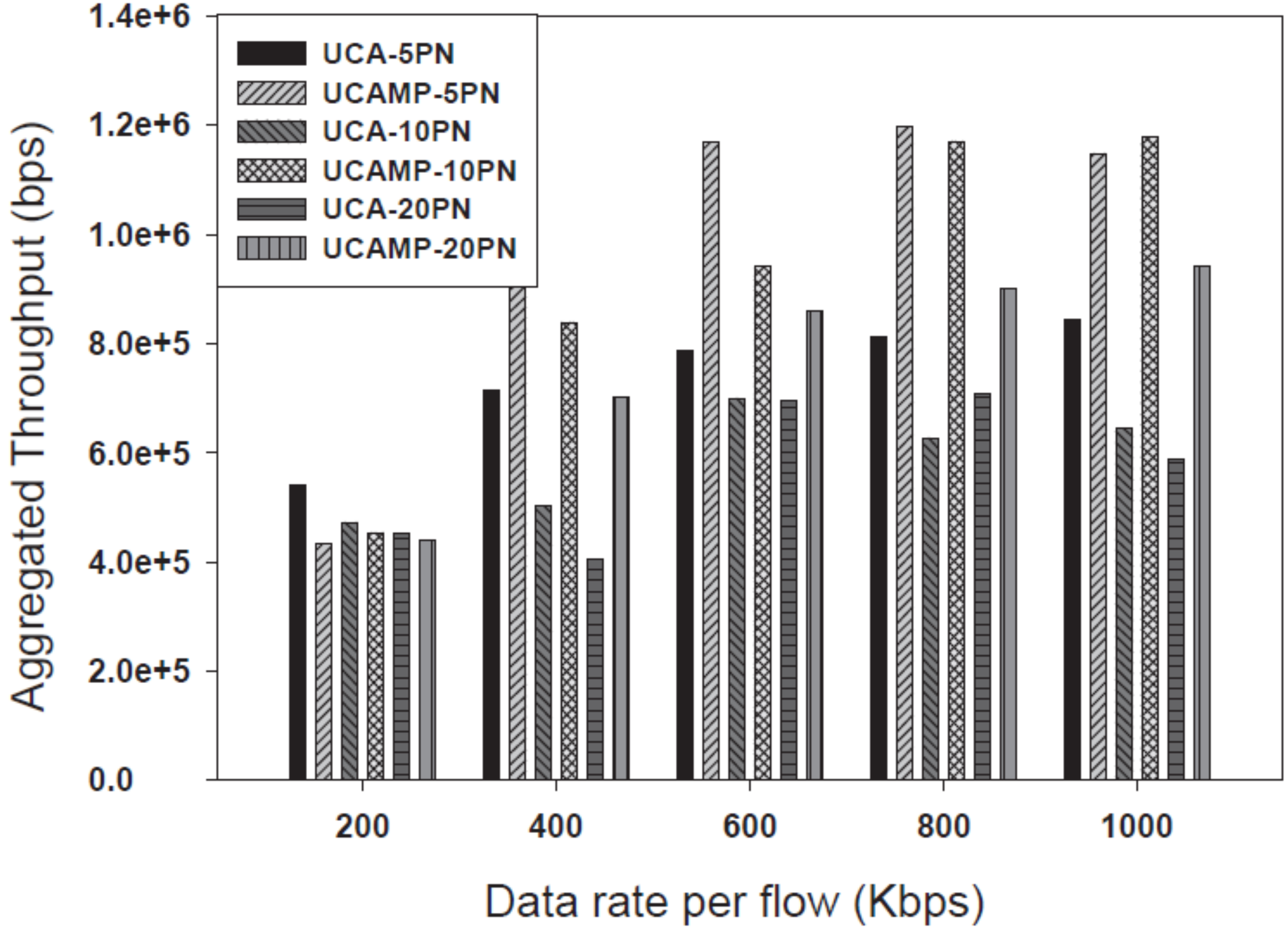
(b) Varying number of PNs



(c) Varying workload

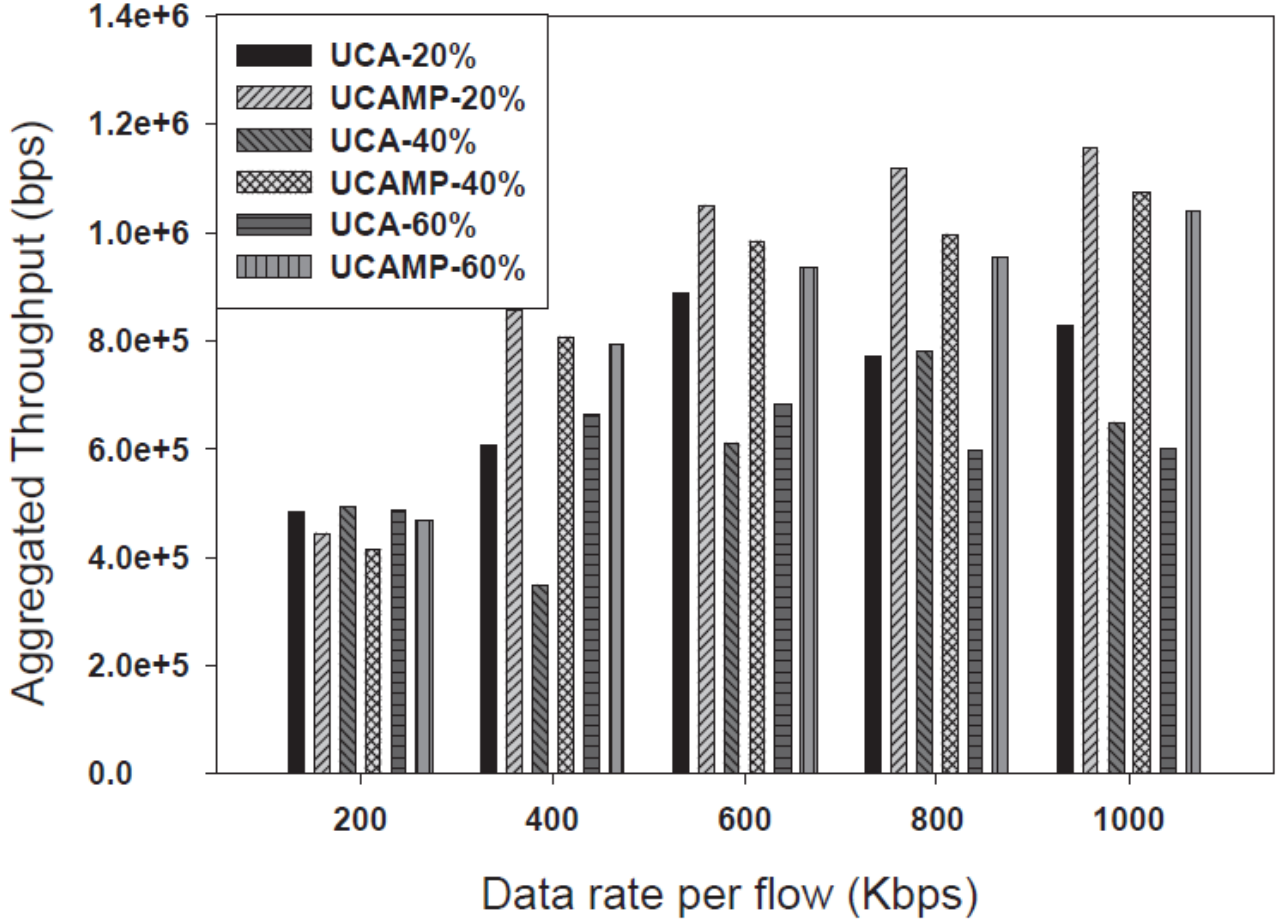
Performance Evaluation

- Multipath Routing – Impact of number of PNs on random topology



Performance Evaluation

- Multipath Routing – Impact of PN workload



Thank you!

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