A SDN Approach to Spectrum Brokerage in Infrastructure-based Cognitive Radio Networks

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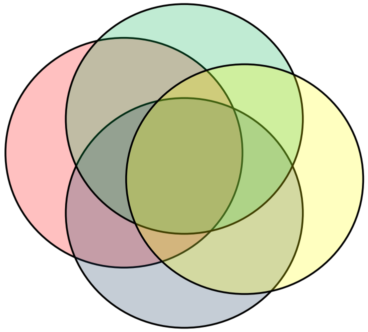
Outline

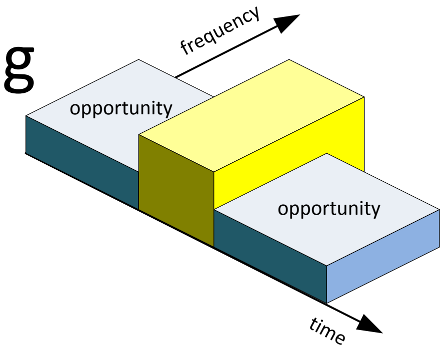
- Motivation,
- System Model,
- Problem Statement,
- Main Contributions,
  - Cloud-based architecture to spectrum brokerage in CRNs,
  - A concrete spectrum allocation algorithm as showcase,
- Evaluation,
- Conclusion.

Motivation

- ***Rapid growth*** in the use of wireless devices such as smart phones in all environments e.g., enterprise and homes, and appearance of **novel applications** like multimedia streaming applications & cloud storage.
- In ***dense wireless deployments*** technologies like WiFi suffer performance issues due to ***insufficient free radio spectrum*** resulting in high contention and interference.



- ***Cognitive Radio*** is a promising approach to overcome such ***spectrum crunch*** by allowing opportunistic spectrum access by secondary users.



Motivation (II)

- Focus of Cognitive Radio (CR) research is mainly on ***co-existence*** issues between primary (PU) & secondary users (SU),
- But ***high-density CR Networks*** will suffer from same problems as we see today with WiFi:
  - ***Insufficient coordination*** in spectrum access between SUs will inevitably result in ***inter-SU interference*** between them leading to low spectral efficiency,
- This work focuses on

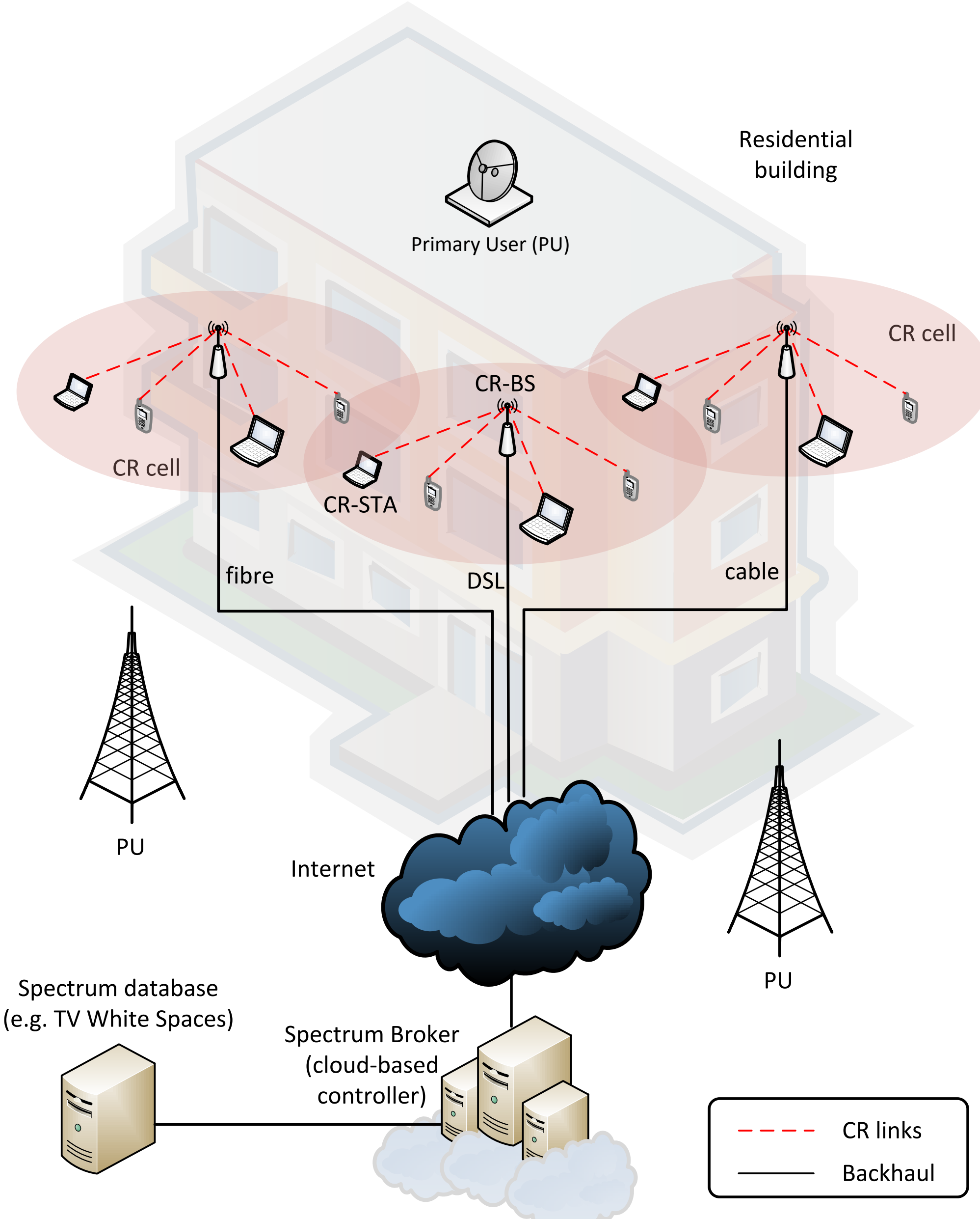
  "fair" SU co-existence.

Source: http://spectrum.ieee.org/telecom/wireless/cognitive-radio-and-game-theory

System Model

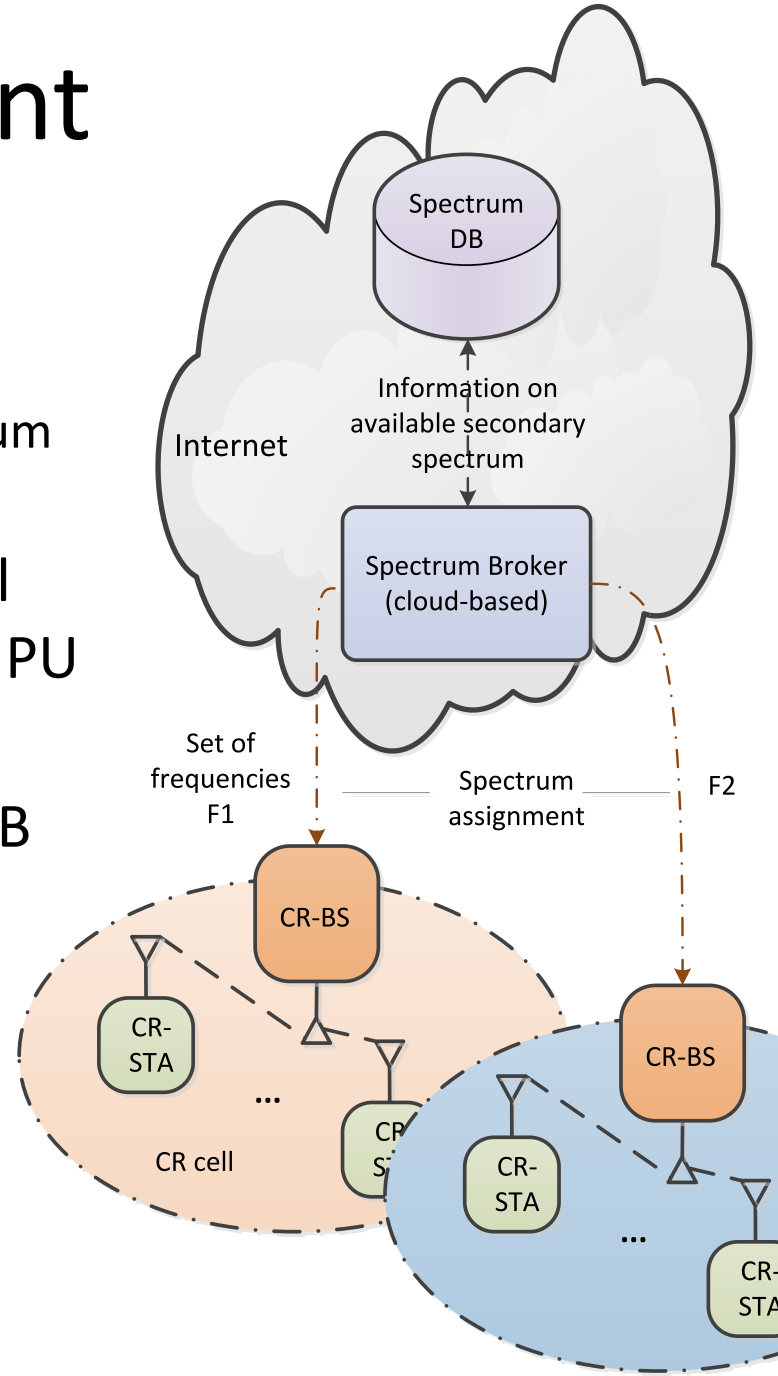
- ***Infrastructure CRN*** in residential area,
- Set of SU cells, i.e. ***CR-BSs*** plus associated ***CR-STAs***,
- CR-BS are connected to Internet by wire (DSL),
- ***PHY layer*** supports usage of fragmented spectrum, e.g. NC-OFDM
- ***Spectrum Broker (SB)***
  - PU protection
  - Spectrum split among SUs

  using ***spectrum database.***



Problem Statement

- ***High density*** deployment leads to interference among co-located SU cells:
  - ***Spectrum Broker (SB)*** ensures “fair” spectrum split and separation
- SB uses spectrum database for inter-cell spectrum allocation on top of the usual PU protection,
- **BUT** ***Internet-scale latencies*** between SB and CR-BSs non negligable → use medium/long-term statistics
  - Which information needed for „fair“ allocation?
  - How to obtain them / distribute decision?

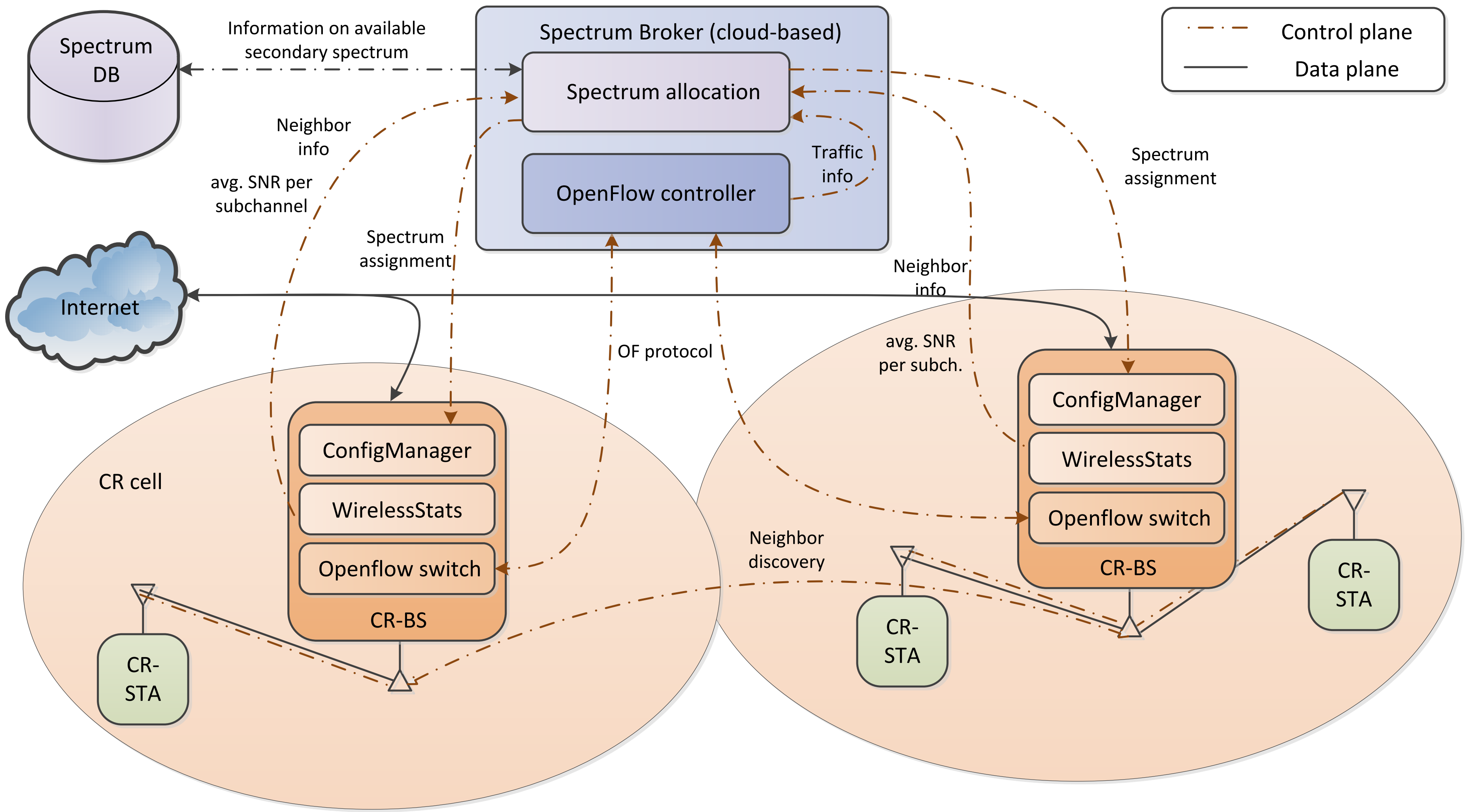


What our main Contributions?

I. Architecture for a ***cloud-based centralized approach*** to spectrum brokerage in CRNs using SDN (OpenFlow),
   - Allowing a ***fine-grained spectrum allocation*** in CRNs taking into account network topology information, dynamically changing traffic and channel conditions.

II. A showcase demonstrates ***spectrum assignment algorithm*** using the above architecture.

Cloud-based Architecture to Spectrum Brokerage in CRN



Architecture Details

- Spectrum Broker uses a ***well-defined API*** towards CR-BS to
  - i) collect wireless statistics from CR-BSs and
  - ii) perform spectrum assignment to CR-BSs.
- Spectrum broker monitors the network traffic on each CR-BS/STA link
  - Chosen abstraction: counting the ***number of active long-lived ("elephant") flows***,
  - Uses the standardized OpenFlow protocol, i.e. each CR-BS is an OF switch.

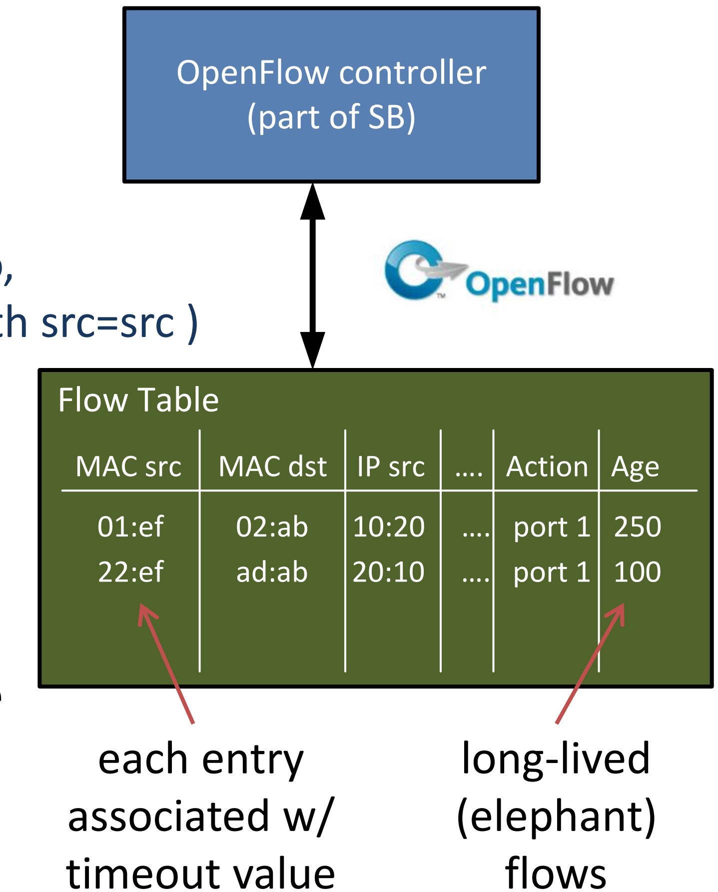
CR-BS API Description

ConfigManager	CR-BS receives configuration commands from the Spectrum Broker (SB) and executes them.
	setSpectrumAllocation(set of subchannels): configures the CR-BS to use the particular spectrum allocation, i.e. the set of subchannels.
WirelessStats	CR-BS reports wireless statistics to the SB.
	getNeighborInfo(): Scans the whole spectrum for neighboring CR-BS beacons and reports their MAC address and average signal strength on each subchannel. ***getClientInfo()***: Reports information about associated CR-STAs, i.e. MAC address and average link SNR per subchannel.
OpenFlow-Switch	Each CR-BS is an OpenFlow (OF) enabled switch. The OF protocol is used to add OF matching rule for each new flow and to count the number of flow entries which allows the SB to estimate the number of active flows on each CR-BS/STA link.

Counting Active Long-lived Flows per Link

- Spectrum broker acts as an ***OpenFlow*** (OF) controller,
- It configures the OF switch in each CR-BS by adding ***OF matching rule*** for each new flow to the OF table:

OFPMatch(in port=in port, eth type=eth type,
ipv4 src=src ip, ipv4 dst=dst ip, ip proto=ip proto,
tcp src=src port, tcp dst=dst port, eth dst=dst, eth src=src)



- OF controller ***periodically polls*** the OF switches to get the no. of entries in the flow table:
  - All flow entries having the same source MAC address identify the flows belonging to the same CR-STA

Showcase: Concrete Spectrum Allocation Algorithm

- Optimal spectrum allocation is NP-C,
- A practical solution faces the following challenges:
  - It needs to ***adapt*** to the dynamically changing secondary spectrum due to PU dynamics,
  - Need to adapt to the changing network traffic and channel conditions to achieve ***fairness*** among ***all network flows*** ~ all flows get the same eff. rate,
  - It should have a ***low-complexity***.

Showcase: Concrete Spectrum Allocation Algorithm (II)

- ***Step 1***: Given set of active flows and average link bitrate for each subchannel we are calculating the ***average flow rate*** in each cell assuming that the total secondary spectrum is available to each cell,
- ***Step 2***: To avoid inter-cell interference co-located cells need to be ***orthogonalized*** in frequency:
  - Given the network topology information we compute the maximal cliques of CR-BS cells,
  - For each cell in each clique the ***relative share of spectrum*** is computed such that each cell within a clique gets the ***same effective average cell flow rate***,
  - We take the minimum value for nodes which are member of more than one clique.

Showcase: Concrete Spectrum Allocation Algorithm (III)

- ***Step 3***: We ***map*** the computed spectrum share ***to the actual spectrum***, i.e. the set of sub-channels to be used, while making sure there is no inter-clique interference.

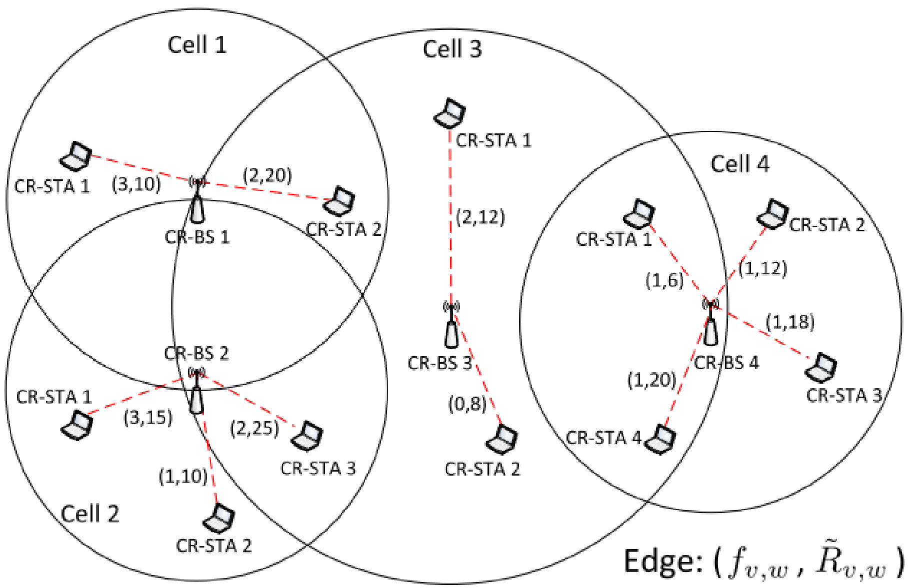
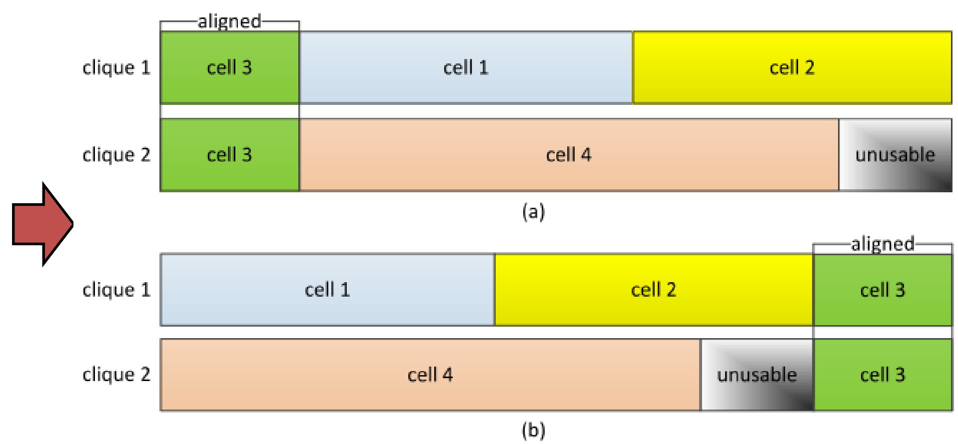


Fig. 3. Illustrative example network.



Evaluation

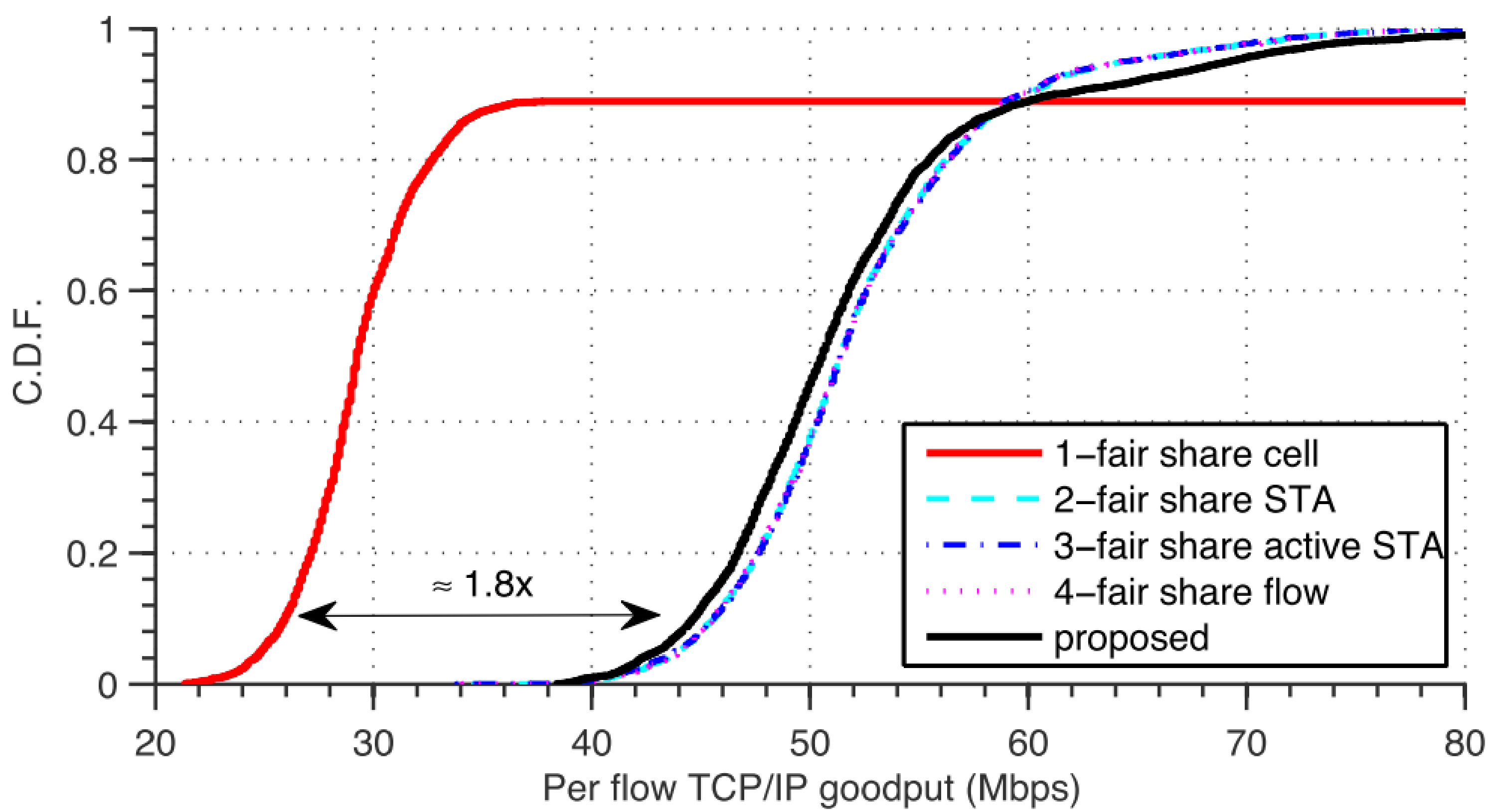
- Methods under study
  - ***Proposed algorithm***,
  - Fair share per cell (base line) ,
  - Fair share per CR-STA,
  - Fair share active CR-STAs only,
  - Fair share active flows only.
- Methodology
  - Mix of system-level emulation (Mininet) and simulation (wireless channel traces)

Parameters used in Evaluation

Parameter	Value
PHY	NC-OFDM (no. Subcarriers=2048, BW=512 MHz, fc=768 MHz)
MAC	TDMA
TX power	20 dBm
Direction	Downlink
Pathloss model	ILM prop (mix of LOS/NLOS)
PU model	Trace
STA placement	Random disc
Flow duration	10s
Emulation software	Linux Ubuntu 12.10, Mininet 2.2, Ryu OFC framework

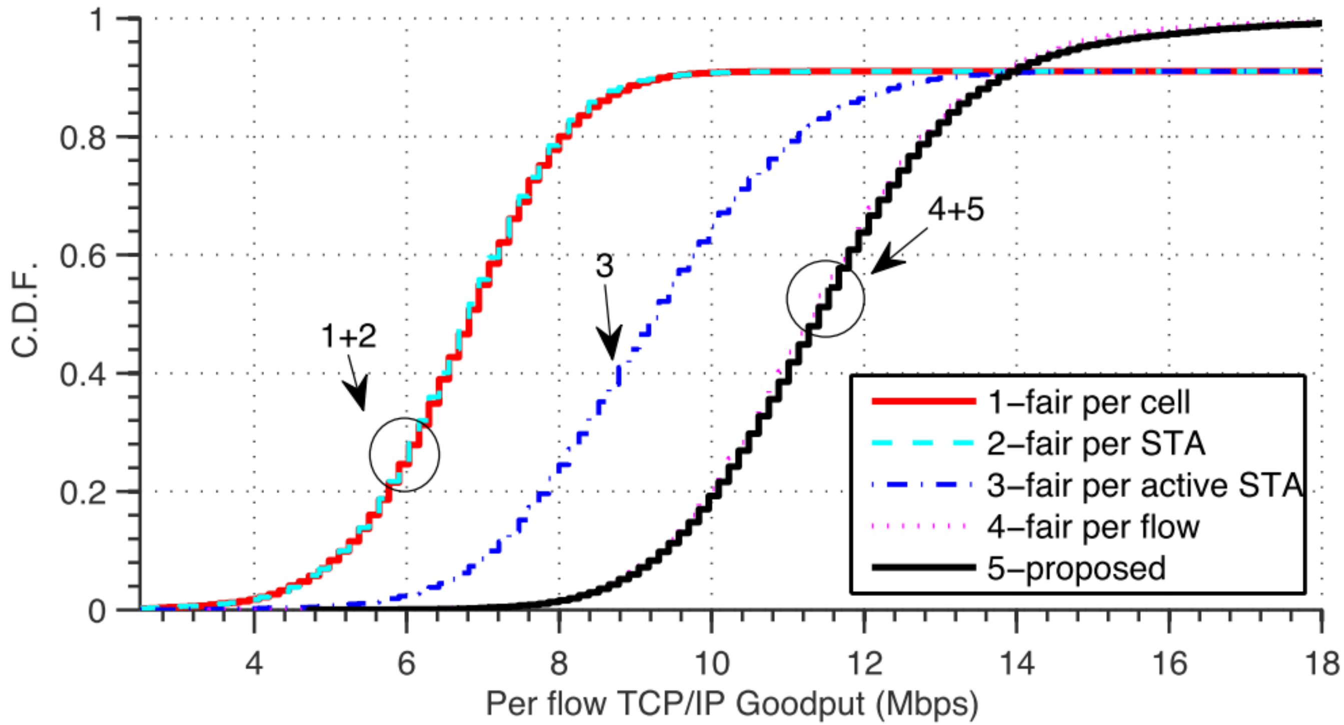
Experiment 1: (Impact of number of CR-STAs in each cell)

- Two overlapping cells with 1 and 8 CR-STAs.
- Single TCP/IP flow at each CR-STA



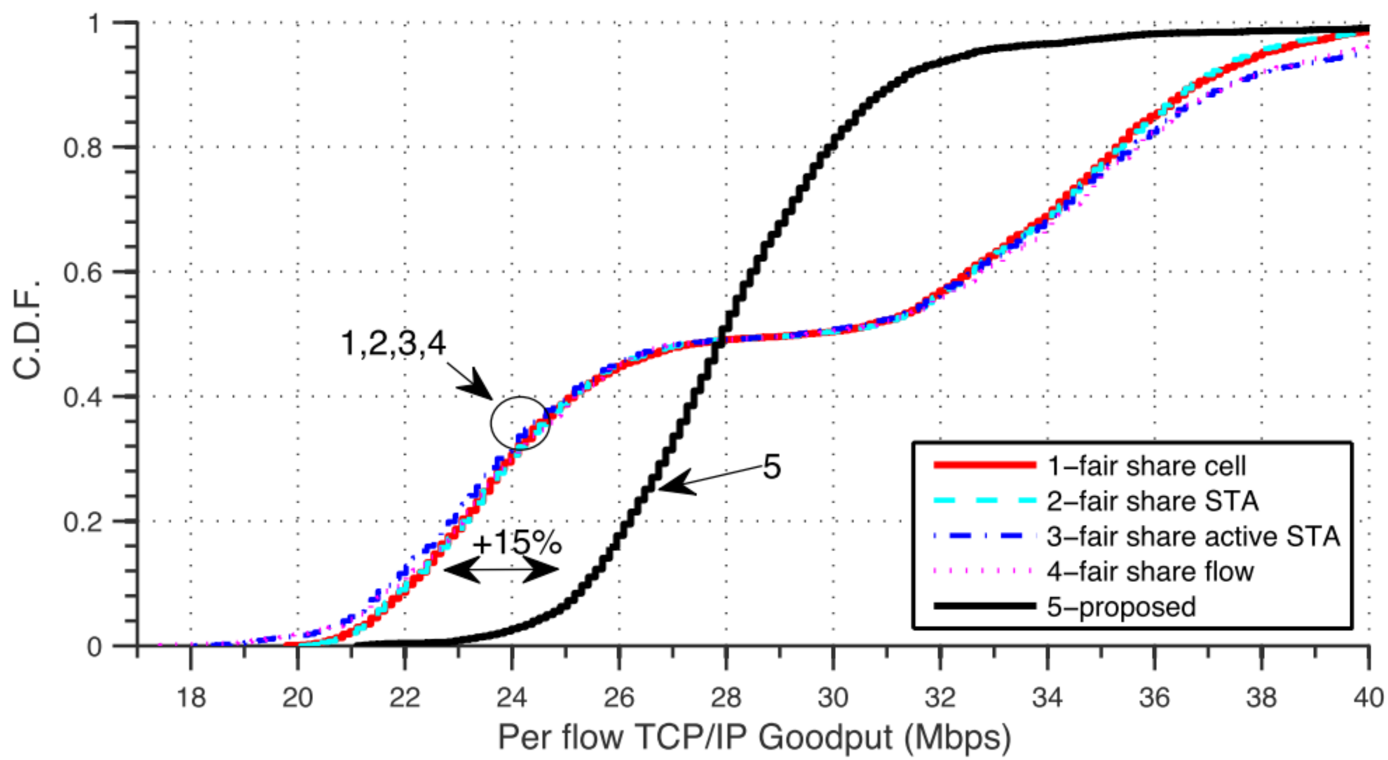
Experiment 2: (Traffic-awareness)

- Traffic model: For each CR-STA in the first cell up to five flows with a probability of 10% each were set up whereas in the second cell each CR-STA had exactly 5 flows.



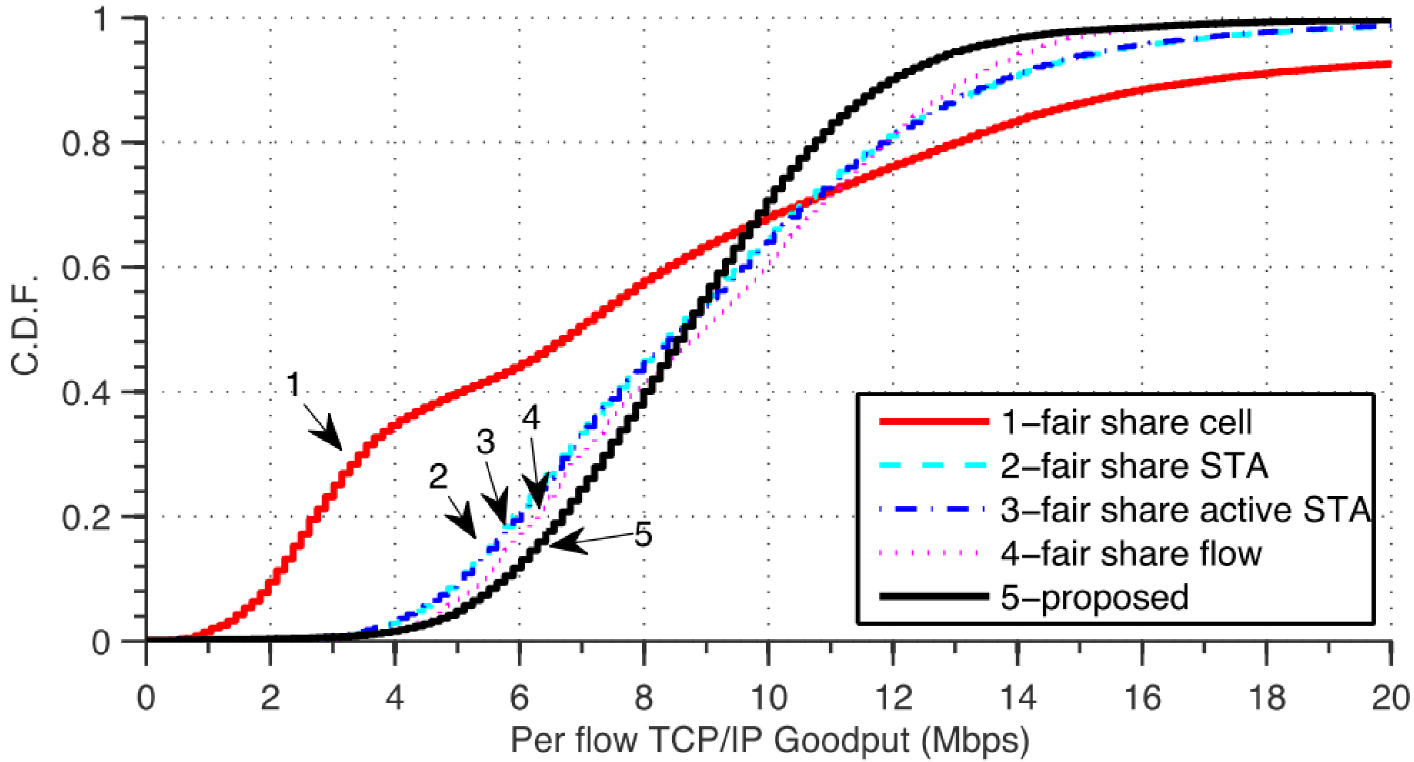
Experiment 3: (Channel awareness)

- CR-STAs in the first cell have a SNR above and in the second cell the CR-STAs have a below average SNR respectively.



Experiment 4: (mix)

- Five cells each with 1, 2, 4, 6 and 8 CR-STAs respectively. At each CR-STA up to five flows with a probability of 50% each were set up.



Conclusions

- We propose an ***architecture for a cloud-based centralized approach to spectrum brokerage*** in CRNs using SDN and OpenFlow which allows a fine-grained spectrum allocation in CRNs taking into account network topology information, dynamically changing traffic as well as channel conditions.
- A ***concrete spectrum assignment algorithm*** using the proposed architecture is presented and evaluated.