Resource Allocation in a Cognitive Digital Home

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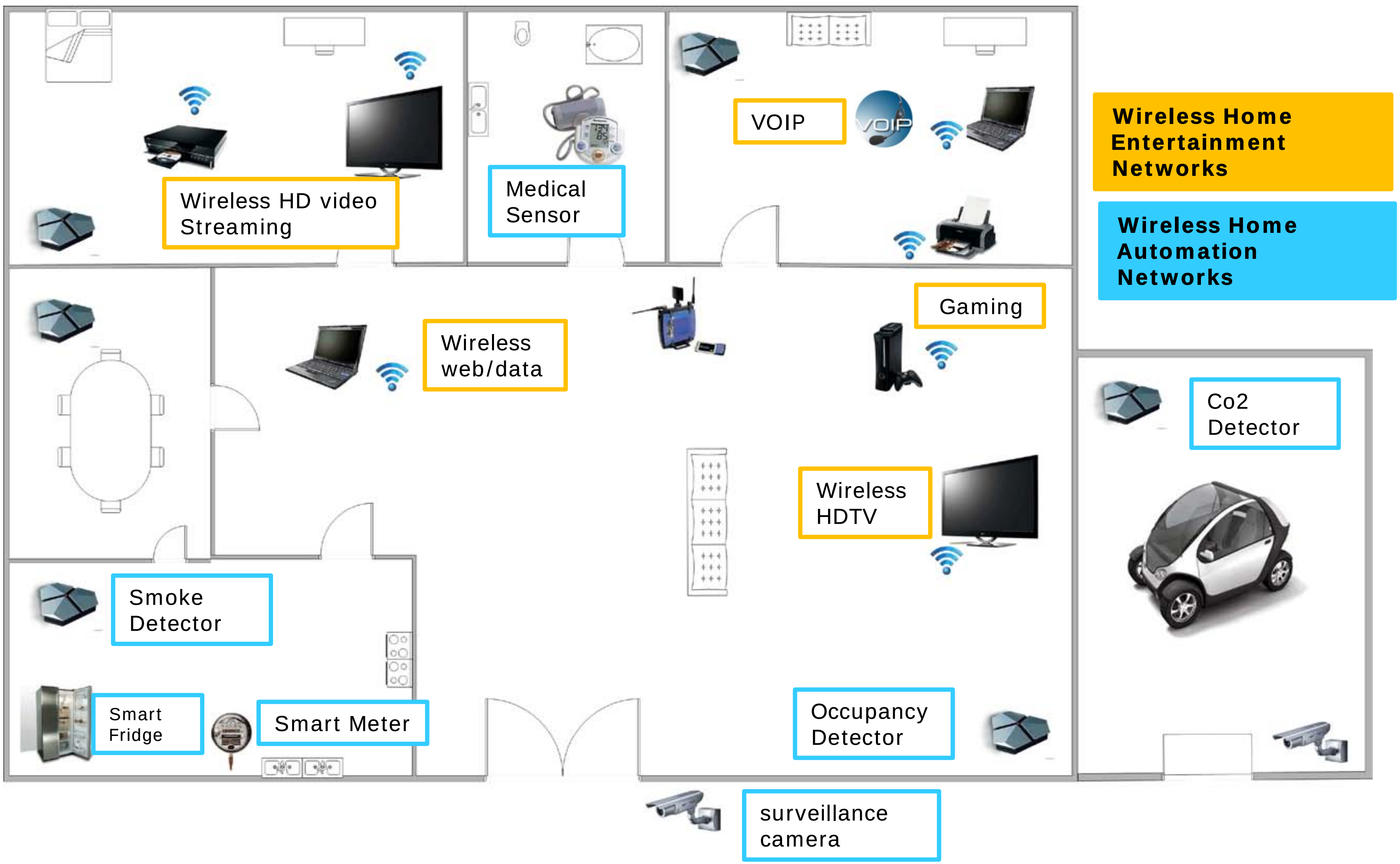
Outline

- Wireless Home Networks
- A Cognitive Digital Home
- Joint Channel and Radio Access Technology Allocation
  - Problems
  - Numerical Results
- Conclusion

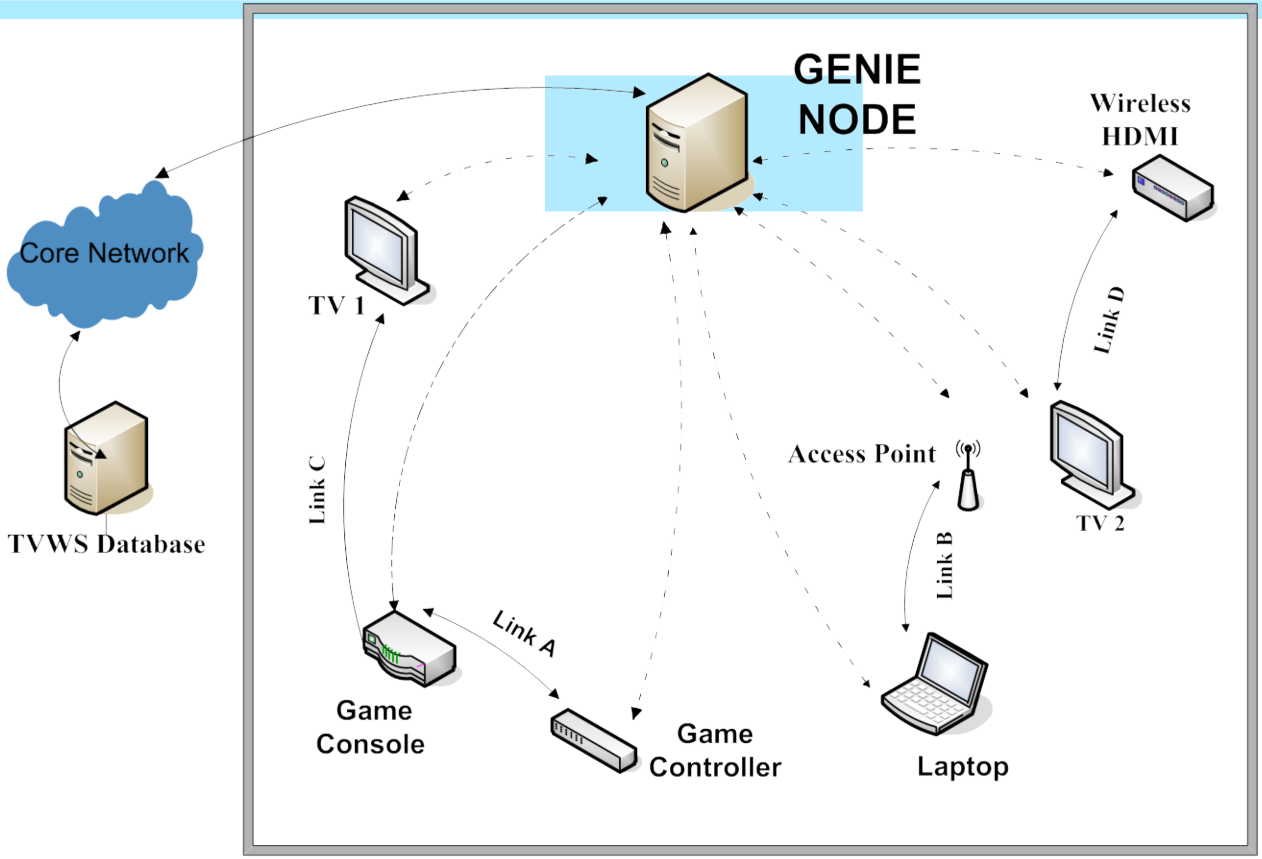
Wireless Home Networks



Characteristics of Wireless Home Networks

- Multiplicity of Radio Access Technologies (RAT)
  - License-exempt: Wi-Fi, Zigbee, Bluetooth, 60GHz Radio, TV White Space, Cognitive radio, etc.
  - License-regulated: Wimax, Femto-cell, etc.
- Noncontiguous spectrum bands
  - From TV white space up to 60GHz radio bands
- Multiplicity of data services in a home environment
  - Voice over IP, Wireless Gaming, P2P, Video, web/data, etc.
- Degrees of freedom
  - Frequency
  - Power
  - Bandwidth
  - **Choice of Radio Access Technology (RAT)**

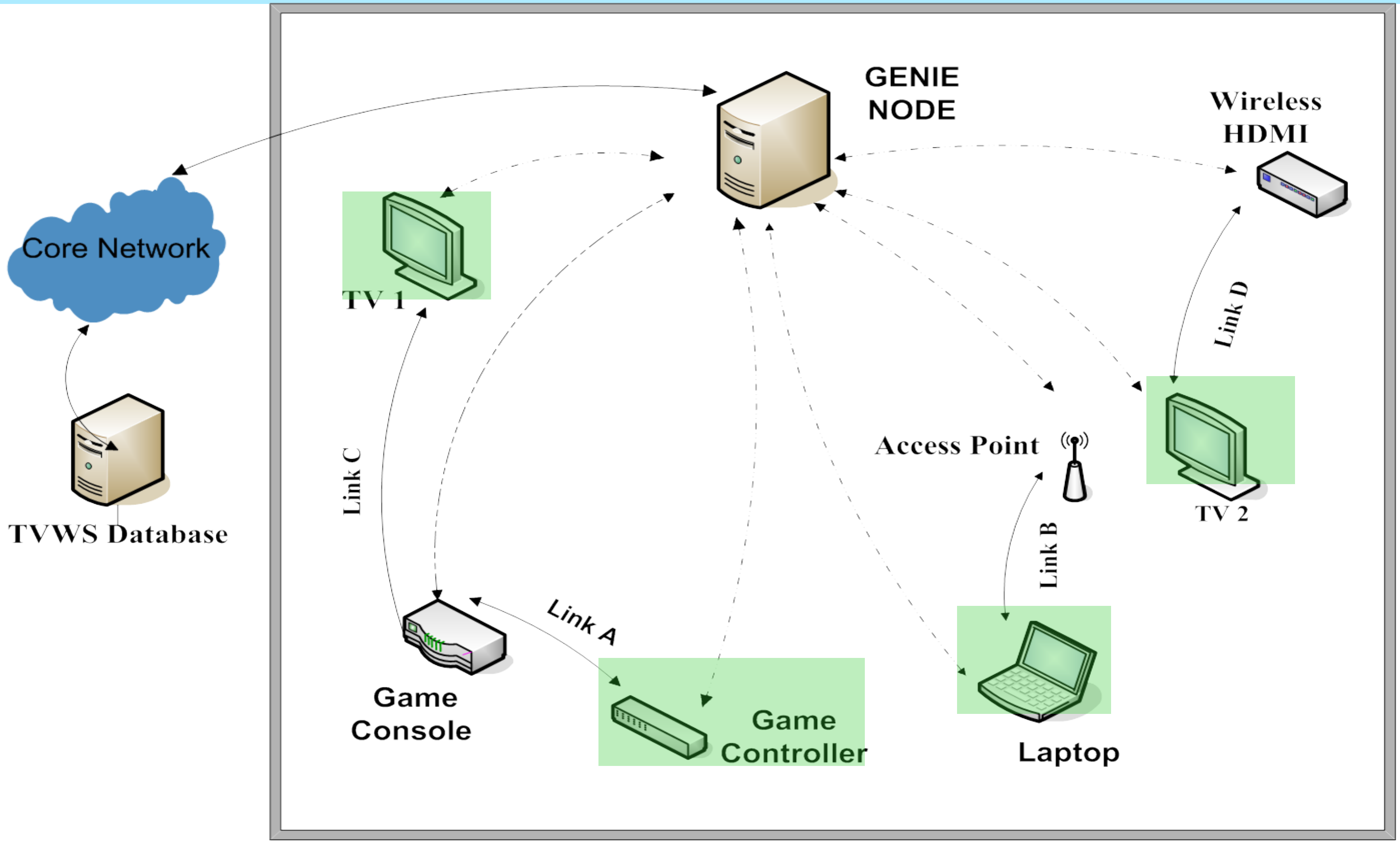
A Cognitive Digital Home (CDH): Architecture



GENIE NODE

- **Maintains the global spectrum availability information**
- **Makes spectrum access decisions**

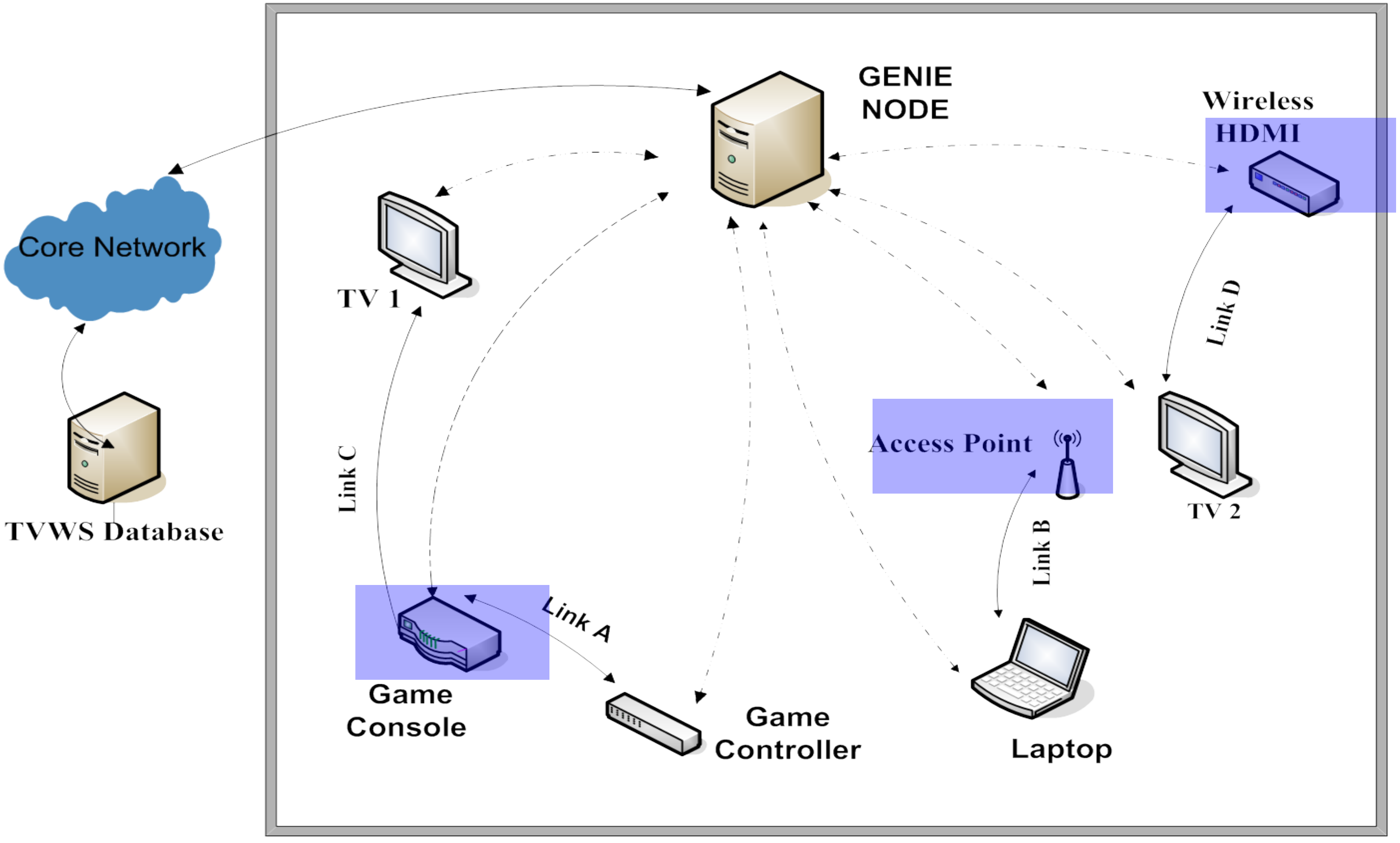
A Cognitive Digital Home (CDH): Architecture



Service Provision Device

- **Provides end services to users**
- **Obtains resources from the Genie Node decision**

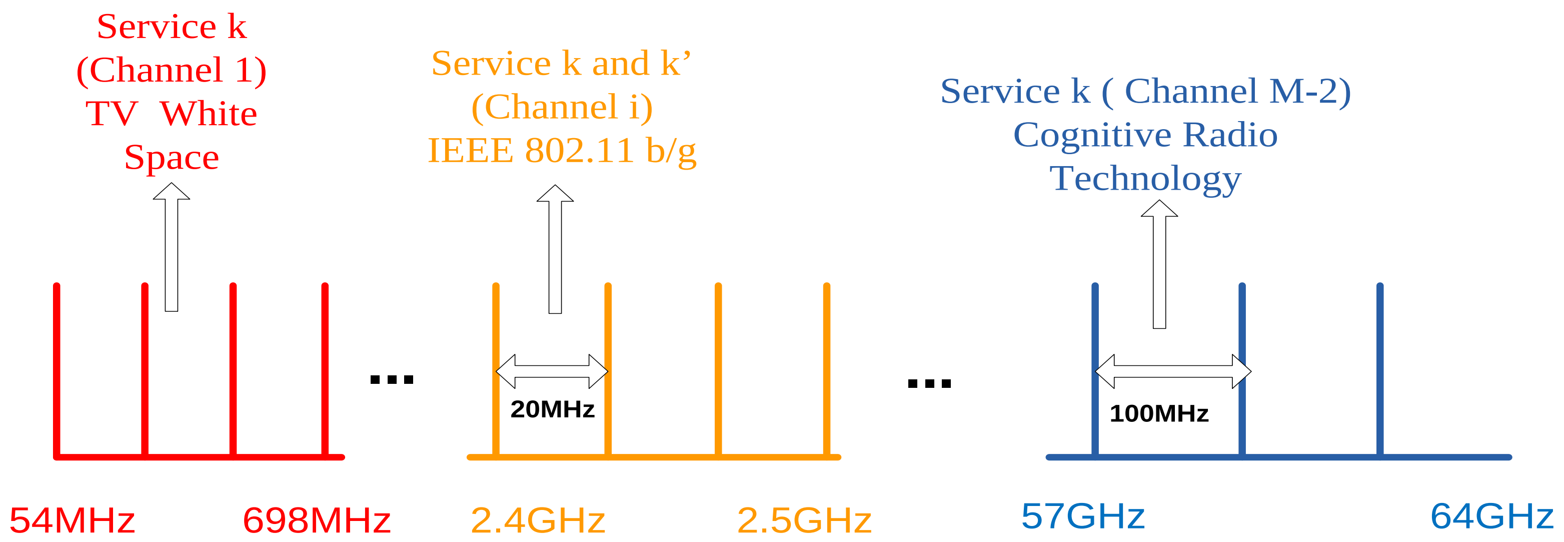
A Cognitive Digital Home (CDH): Architecture



Relay and Wireless Access Devices

Provides relay and wireless access service to service provision devices

A Cognitive Digital Home: *Resources*



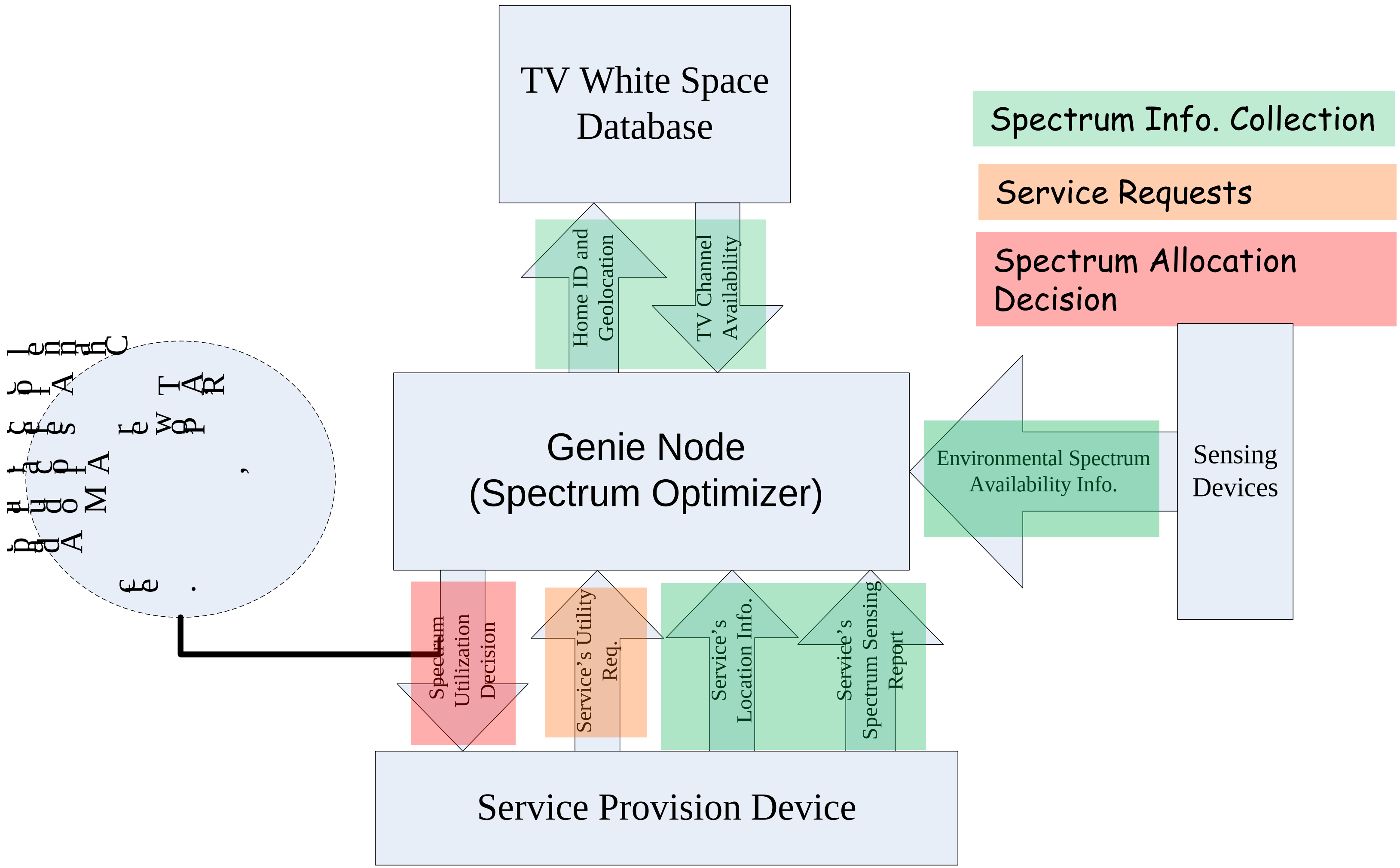
- Resources: A 3-tuple of frequency, bandwidth and RAT
- All usable spectrum in home environment

Multi-platform Radio Devices

Multiple RATs on a Multi-platform Radio Device

- Legacy: WiFi, Bluetooth, TV White spaces, etc.
  - Access to limited number of channels in specific spectrum regions
    - Over-crowded spectrum bands
- Cognitive Radio
  - Accesses a channel orthogonally ---- OFDMA (Noncontiguous)
    - Reduce system complexity and signaling overhead
  - Access to all the channels in a CDH
    - Provide channel access flexibility

A Framework for Resource Allocation in a CDH



- Multi-Platform Radios, Genie Node, Sensing Devices (Not currently considered)

Joint Channel and RAT Allocation Problem 1 : *Max Sum Rate*

$$\max_{\mathbf{L}} \sum_{k \in \mathcal{K}} \sum_{i \in \mathcal{M}} \sum_{t \in \mathcal{T}} R(k,i,t) l(k,i,t)$$

subject to

$$\sum_{i \in \mathcal{M}} \sum_{t \in \mathcal{T}} R(k,i,t) l(k,i,t) \geq R_k^{min}, \quad \forall k \in \mathcal{K}$$

Individual Rate Constraint for each service

$$P(k,i,t) = P_t, \quad \forall k \in \mathcal{K}, \forall i \in \mathcal{M}, \forall t \in \mathcal{T}$$

Transmit power is only determined by RAT

$$\sum_{i \in \mathcal{M}} \sum_{t \in \mathcal{T}} P(k,i,t) \lceil l(k,i,t) \rceil \leq P_k^{max}, \quad \forall k \in \mathcal{K}$$

Individual Transmit Power Constraint for each service

$$l(k,i,t) \in \begin{cases} \{0,1\} & \text{if } t = \text{CR}, \forall i \in \mathcal{M}, \forall k \in \mathcal{K} \\ [0,1] & \text{if } t \neq \text{CR}, \forall i \in \mathcal{M}_t, \forall k \in \mathcal{K} \\ 0 & \text{otherwise} \end{cases}$$

$$\sum_{k \in \mathcal{K}} \sum_{t \in \mathcal{T}} l(k,i,t) \leq 1, \forall i \in M$$

Spectrum usage constraint

Joint Channel and RAT Allocation Problem 2 : *Max Service Capacity*

$$\max_{\mathbf{L}} \sum_{k \in \mathcal{K}} u\Big(\sum_{i \in \mathcal{M}} \sum_{t \in \mathcal{T}} R(k,i,t) l(k,i,t) - R_k^{min}\Big)$$

u(.): step function

$$subject\ to\quad P(k,i,t) = P_t,\ \ \forall k \in \mathcal{K}, \forall i \in \mathcal{M}, \forall t \in \mathcal{T}$$

Transmit power is only determined by RAT

$$\sum_{i \in \mathcal{M}} \sum_{t \in \mathcal{T}} P(k,i,t) \lceil l(k,i,t) \rceil \leq P_k^{max},\ \ \forall k \in \mathcal{K}$$

Individual Transmit Power Constraint for each service

$$l(k,i,t) \in \begin{cases} \{0,1\} & \text{if } t = \text{CR},\ \forall i \in \mathcal{M},\ \forall k \in \mathcal{K} \\ [0,1] & \text{if } t \neq \text{CR},\ \forall i \in \mathcal{M}_t,\ \forall k \in \mathcal{K} \\ 0 & \text{otherwise} \end{cases}$$

$$\sum_{k \in \mathcal{K}} \sum_{t \in \mathcal{T}} l(k,i,t) \leq 1,\ \forall i \in M$$

Spectrum usage constraint

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Joint Channel and RAT Allocation Problem 3 : *Max Min Rate*

Maxmin Fairness among Elastic Services

$$\max_{\mathbf{L}} \ r$$

$$\textit{subject to} \quad r \leq \sum_{i \in \mathcal{M}} \sum_{t \in \mathcal{T}} R(k,i,t) l(k,i,t) \ , \forall k \in \mathcal{K}$$

$$P(k,i,t) = P_t, \ \ \forall k \in \mathcal{K}, \forall i \in \mathcal{M}, \forall t \in \mathcal{T}$$

Transmit power is only determined by RAT

$$\sum_{i \in \mathcal{M}} \sum_{t \in \mathcal{T}} P(k,i,t) \lceil l(k,i,t) \rceil \leq P_k^{max}, \ \ \forall k \in \mathcal{K}$$

Individual Transmit Power Constraint for each service

$$l(k,i,t) \in \begin{cases} \{0,1\} & \text{if } t = \text{CR}, \ \forall i \in \mathcal{M}, \ \forall k \in \mathcal{K} \\ [0,1] & \text{if } t \neq \text{CR}, \ \forall i \in \mathcal{M}_t, \ \forall k \in \mathcal{K} \\ 0 & \text{otherwise} \end{cases}$$

Spectrum usage constraint

$$\sum_{k \in \mathcal{K}} \sum_{t \in \mathcal{T}} l(k,i,t) \leq 1, \ \forall i \in M$$

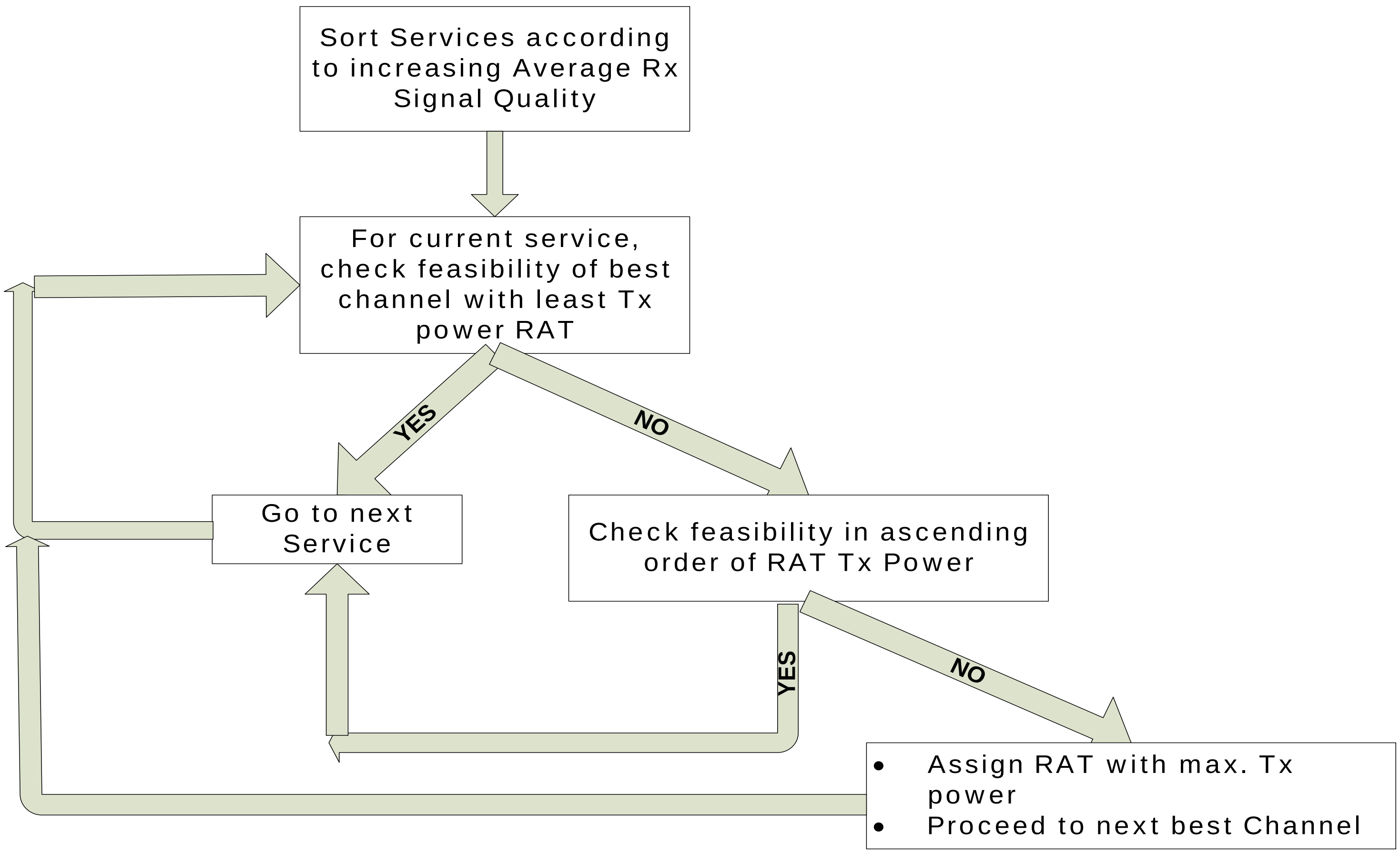
Heuristic Algorithm: *Max Sum Rate & Max Service Capacity*

RAT First Joint Channel and RAT Allocation(RF-JCRA)

- Stage 1: Minimum Rate Allocation
  - Allocate resources to meet services’ minimum required rates
- Stage 2: Marginal Rate Allocation
  - Allocate marginal resources to maximize the sum rates

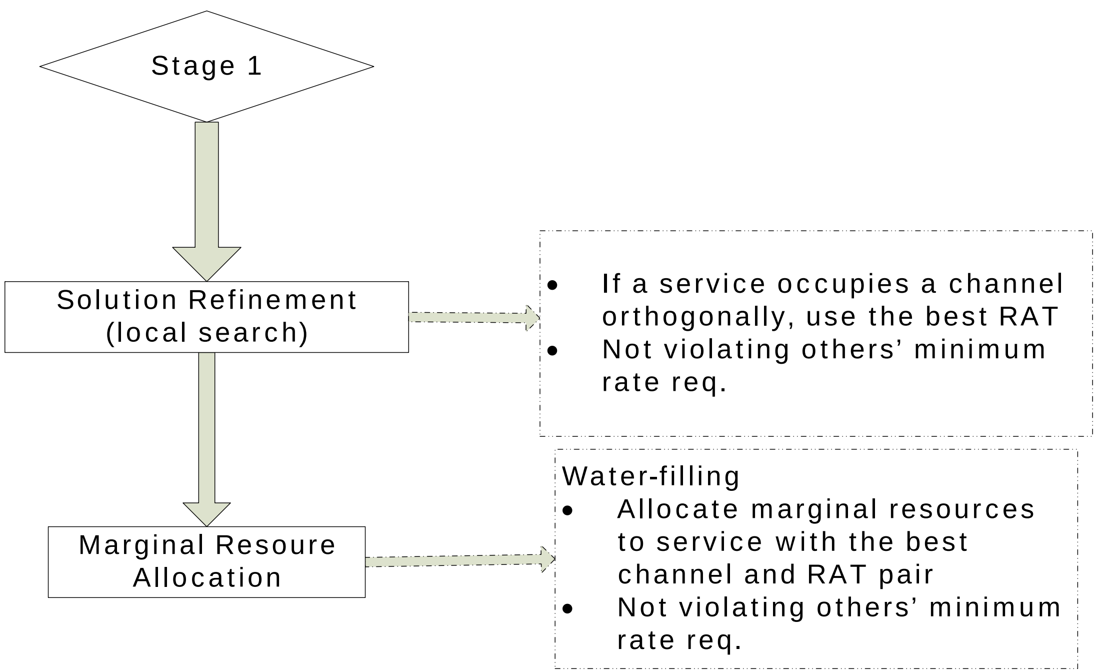
Stage 1: Min. Rate Allocation

- Heuristic based on multiple choice knapsack problem



Stage 2: Marginal Rate Allocation

- Solution Refinement based on local search in mixed-integer programming
  - improve an identified feasible solution
- Marginal Resource Allocation
  - Water-filling



Numerical Result: *Setup*

- Channels:

CH. #	1	2	3	4	5	6	7
Freq.(GHz)	2.412	2.437	2.462	2.484	57.1	57.2	57.3
Bandwidth(MHz)	20	20	20	20	100	100	100

- Wi-Fi operates on the first 4 channels
- CR operates on all the channels
- RATs employs constant transmit power on each channel

RAT	Bluetooth	Wi-Fi	CR
Power(mW)	10	30	60

Numerical Result 1: (An exemplary CDH)

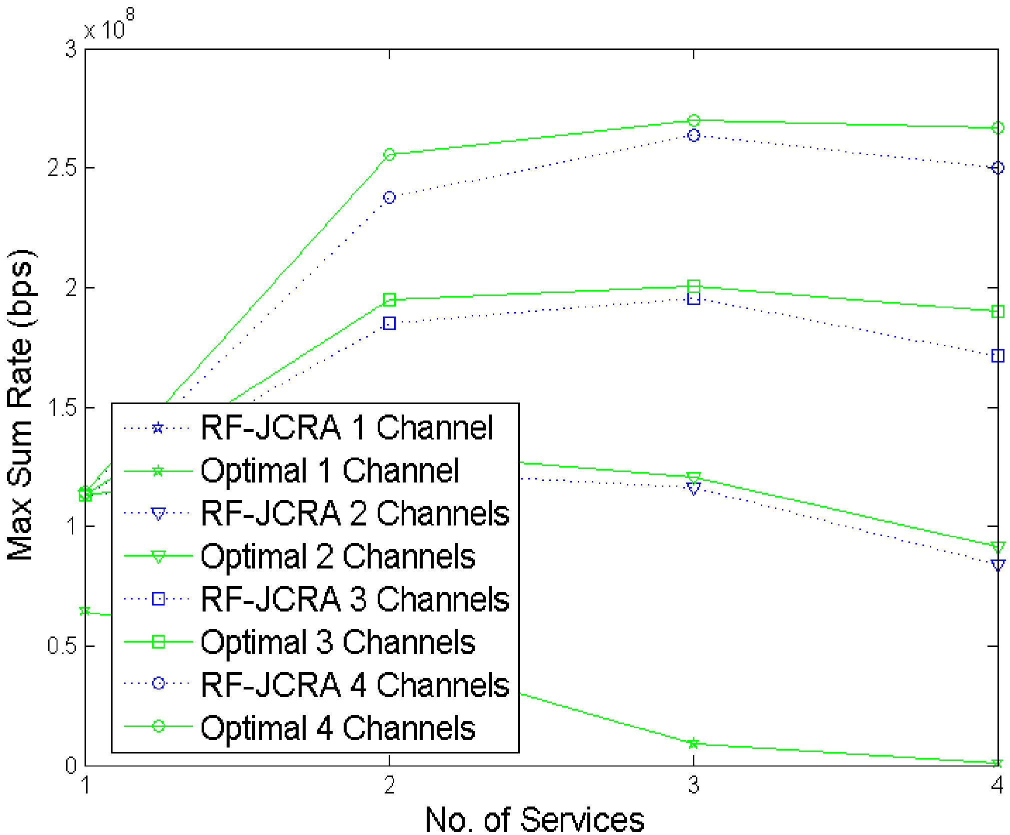
- 4 services, A (gaming controlling) , B (Wireless Internet) , C (gaming video) and D(Wireless HDTV)
- Constraints

Service	Gaming Controlling(A)	Wireless Internet (B)	Gaming Video (C)	Wireless HDTV(D)
Rate Req. (Mbps)	1	10	25	60
Max. Device Transmit Power(Mw)	10	30	100	300
Accessible Channels	1~4	1~4	1~7	1~7
Link length (m)	8	8	8	8

- Results

CH. & RAT	1~4(BT)	1(WiFi)	1,2(WiFi)	2~4(WiFi), 5~7(CR)
Achieved Rates (Mbps)	1	13	26	71

Numerical Result 2: *Max Sum Rate*



- Optimal: $\mathcal{O}(|\mathcal{K}||\mathcal{M}|P)$

$$P = \Big(\sum_{t\in\mathcal{T}_{\mathcal{O}}} |\mathcal{K}| + \sum_{t\in\mathcal{T}_{\mathcal{L}}} \sum_{i=1}^{|\mathcal{K}|} \binom{|\mathcal{K}|}{i}\Big)^{|\mathcal{M}|}$$

- RF-JCRA: $\mathcal{O}(|\mathcal{K}||\mathcal{M}|^2|\mathcal{T}|)$

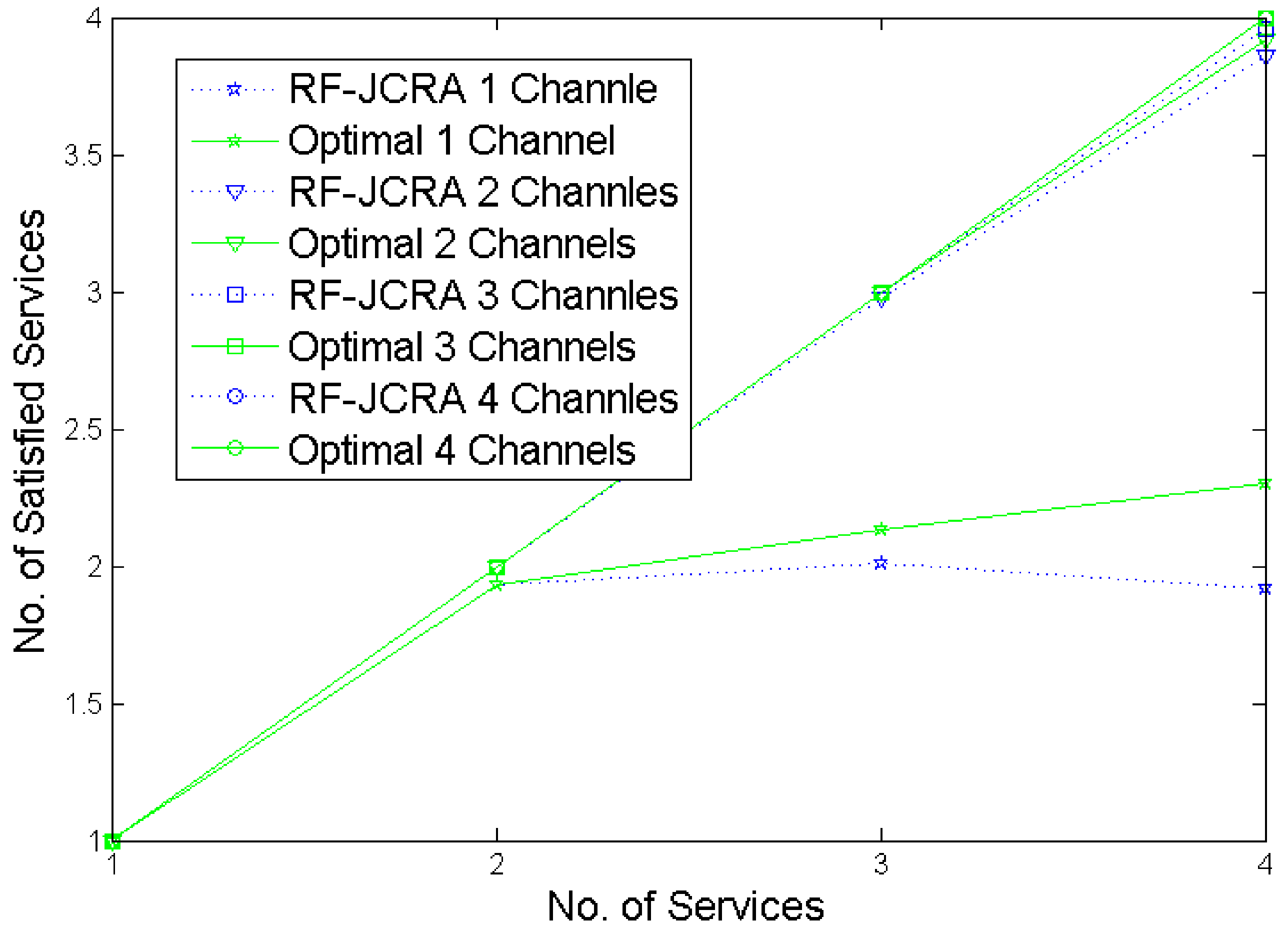
\# of services

\# of channels

\# of RATs

- RAT: **CR and Wi-Fi**
- Link Distances: Uniformly generated in 5~10m
- Service Power Constraints vector: [100 200 300 400] mW
- Rate Constraints: 15Mbps for each service

Numerical Result 3: *Max Service Capacity*



Conclusion

- Proposed a novel framework for resource allocation in wireless home networks: CDH
  - Radio access technology as a new dimension of allocation
- Proposed efficient algorithms for 3 joint channel and RAT allocation problems in CDH
- Future work: Decentralized algorithms

Q&A