Joint Rate and Power Control using Distributed Algorithms in Cognitive Radio Networks

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AGENDA

- Objective
- Motivation
- System Model
- Power Control in Cognitive Radio Network
- Distributed Power Control Algorithms
- Proposed Algorithm
- Simulation Results
- Conclusions
- Future work

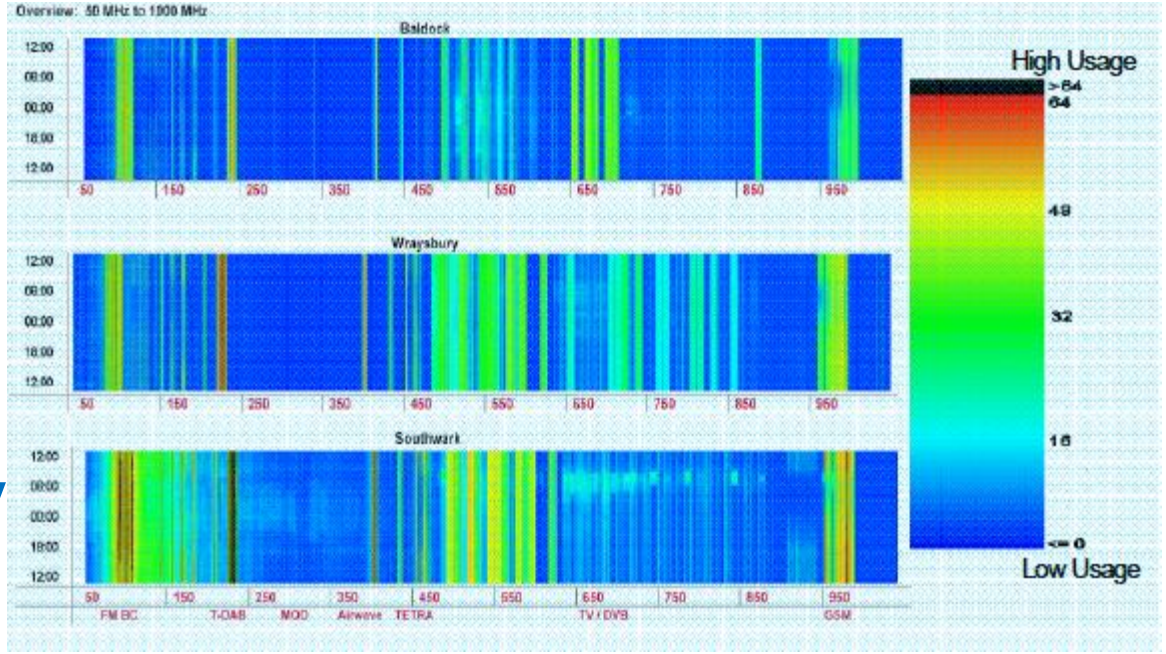
Objective

- **Power control in the Cognitive Radio (CR) Network in order to:**
  - **To maintain the QoS of licensed primary user (PU) by avoiding interference**
  - **To maximize the energy efficiency of the system**
  - **To maintain the QOS of the CR users**

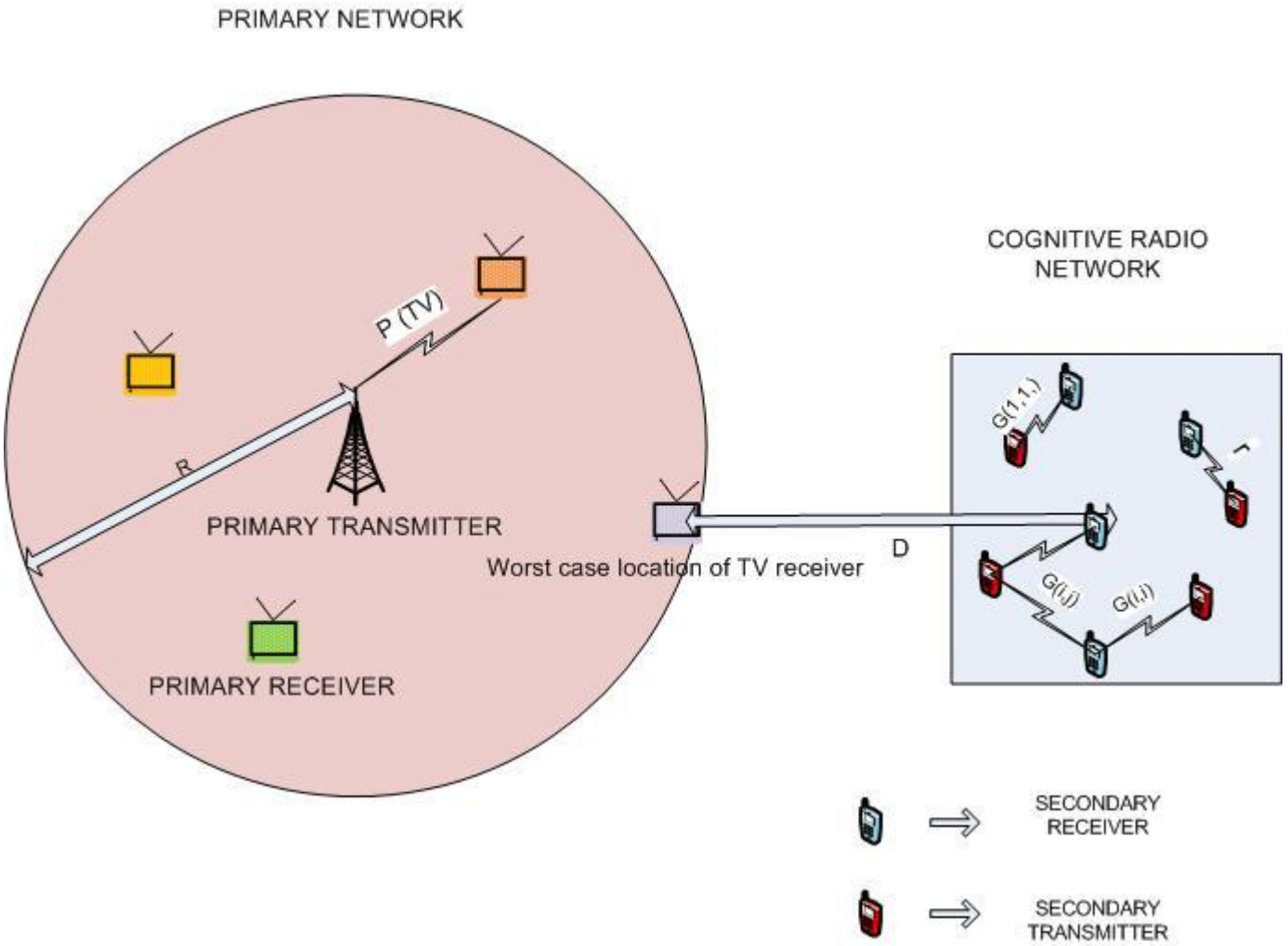
- **To propose a Joint Rate and Power Control algorithm using the distributed algorithm in CR network**

Motivation

- Why Cognitive Radio networks?
- ➢ Frequency Scarcity- As Radio Frequency band is limited
- ➢ Spectrum Underutilisation- Only 15-30% of Spectrum is used at a specific time and space- Ofcom Report
- ➢ Key aspects:
- Awareness
- Adaptivity
- Reliability
- Reconfigurability
- Intelligence



System Model



Why Power Control in necessary?

- Power Control-
  - ✓ Essential for avoiding Interference
  - ✓ To maintain QoS
  - ✓ To save energy of Battery powered mobile equipments- long life

- QoS is measured by
  - Cumulative Interference at Primary User
  - Link Quality of the Secondary User

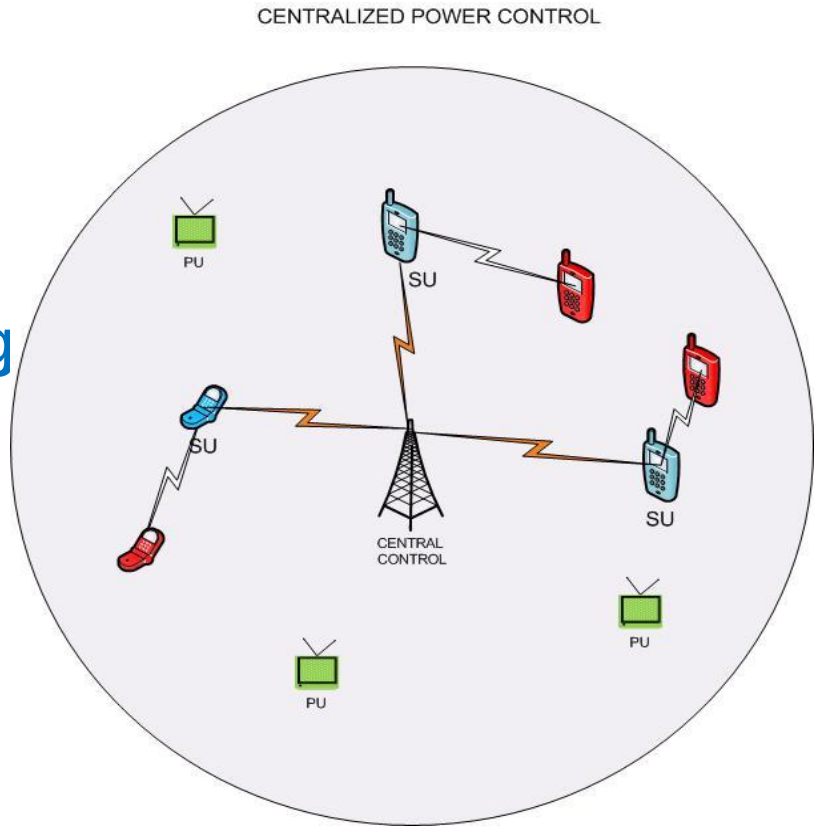
Power Control Types

- **Centralized Power Control**

  Eg.Using Fuzzy Logic System

Drawbacks:

- **Need a central controller and global information**
- **Extensive Control Signalling**
- **Difficult to implement in ad hoc networks**



Distributed Power Control

- Each user control the TX power by local information
- Distributed Power Control

  ->Iterative Algorithms

- Genie Aided- TX power of each SU is determined by DPC algorithm.
- If Interference level is high, the genie near PU informs SU

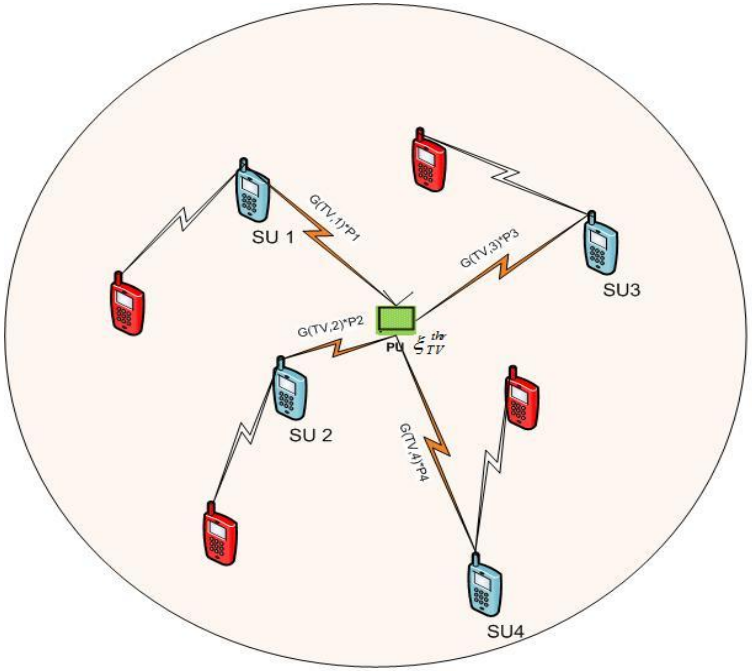
QOS Requirements

- **Interference Temperature of PU**

$$\xi_{tv} = \sum_{i=1}^{N} G_{TV,i} P_i \leq \xi_{TV}^{thr}$$

- **Received SINR of SU**

$$\gamma_{SU_i} = \frac{W}{R_i} \frac{G_{i,i} P_i}{\sum_{j=1, j\neq i}^{N} G_{i,j} P_j + G_{i,TV} P_{TV} + N_0} \geq \gamma_{SU}^{thr}$$



- **The Minimum TX power of SU can be given by**

$$P_i \geq \gamma_{SU}^{thr} \left(\sum_{j=1, j\neq i}^{N} \frac{G_{i,j}}{G_{i,i}} P_j + \frac{G_{i,TV}}{G_{i,i}} P_{TV} + \frac{N_0}{G_{i,i}} \right)$$

Distributed Constrained Power Control(DCPC)

- **Iterative Power Control Method(DPC):**

$$P_i(t+1) = \frac{\gamma_{SU}^{thr}}{G_{i,i}} \left(\sum_{j=1, j\neq i}^{N} G_{i,j} P_j(t) + G_{i,TV} P_{TV} + N_0 \right)$$

$$= \frac{\gamma_{SU}^{thr}}{\gamma_{SU_i}(t)} P_i(t), t = 0,1,.....$$

Maximum Transmission Power Limit:

$$0 \le P_i \le P_{SU}^{\max}, i \in \{1,2,.....,, N\}$$

Power limited form of Iterative Method(DCPC)

$$P_i(t+1) = \min\left\{ \frac{\gamma_{SU}^{thr}}{\gamma_{SU_i}(t)} P_i(t), P_{SU}^{\max} \right\}, t = 0,1,....$$

Drawback: TX power reaches maximum even if the user cannot achieved minimum required SINR

Generalized DCPC(GDCPC)

- If SINR cannot be achieved, power is reduced with in the power range.
- Saves energy
- Reduces interference

$$P_i(t+1) = \begin{cases} \dfrac{\gamma_{SU}^{thr}}{\gamma_{SU_i}(t)} P_i(t), if \ \dfrac{\gamma_{SU}^{thr}}{\gamma_{SU_i}(t)} P_i(t) \le P_{SU}^{max} \\ \overline{P}, if \ \dfrac{\gamma_{SU}^{thr}}{\gamma_{SU_i}(t)} P_i(t) > P_{SU}^{max} \end{cases}$$

$$0 \le \overline{P} \le P_{SU}^{max}$$

- If $\overline{P} = P_{SU}^{max}$, GDCPC becomes equal to DCPC
- Beaconing concept -> To Guarantee priority of PU

Autonomous DCPC (ADCPC)

- In DCPC and GDCPC, QoS of Primary Receiver is not considered
- In the ADCPC System, interference by all the SU is translated in to individual constraint for each SU
- Condition for QoS of PU: $G_{TV,i}P_i \leq \frac{\xi_{TV}^{thr}}{N}, i \in \{1,2,....,N\}$
- Ad-hoc Routing protocol-> For Identifying the number of SU

Autonomous DCPC

- **Maximum TX Power constraint is enforced to each user**

$$P_{SU_i}^{\max} = \min\left\{ P_{SU}^{\max}, \frac{\xi_{TV}^{thr}}{G_{TV,i} N} \right\}$$

- **Transmission Power updating rule**

$$P_i(t+1) = \min\left\{ \frac{\gamma_{SU}^{thr}}{\gamma_{SU_i}(t)} P_i(t), \min\left\{ P_{SU}^{\max}, \frac{\xi_{TV}^{thr}}{G_{TV,i} N} \right\} \right\}$$

Autonomous GDCPC

- **Transmission Power updating rule:**

$$P_i(t+1) = \begin{cases} \dfrac{\gamma_{SU}^{thr}}{\gamma_{SU_i}(t)} P_i(t), if \ \dfrac{\gamma_{SU}^{thr}}{\gamma_{SU_i}(t)} P_i(t) \le P_{SU_i}^{\max} \\ \overline{P}_i, if \ \dfrac{\gamma_{SU}^{thr}}{\gamma_{SU_i}(t)} P_i(t) > P_{SU}^{\max} \end{cases}$$

- **Arbitrary chosen power value:**

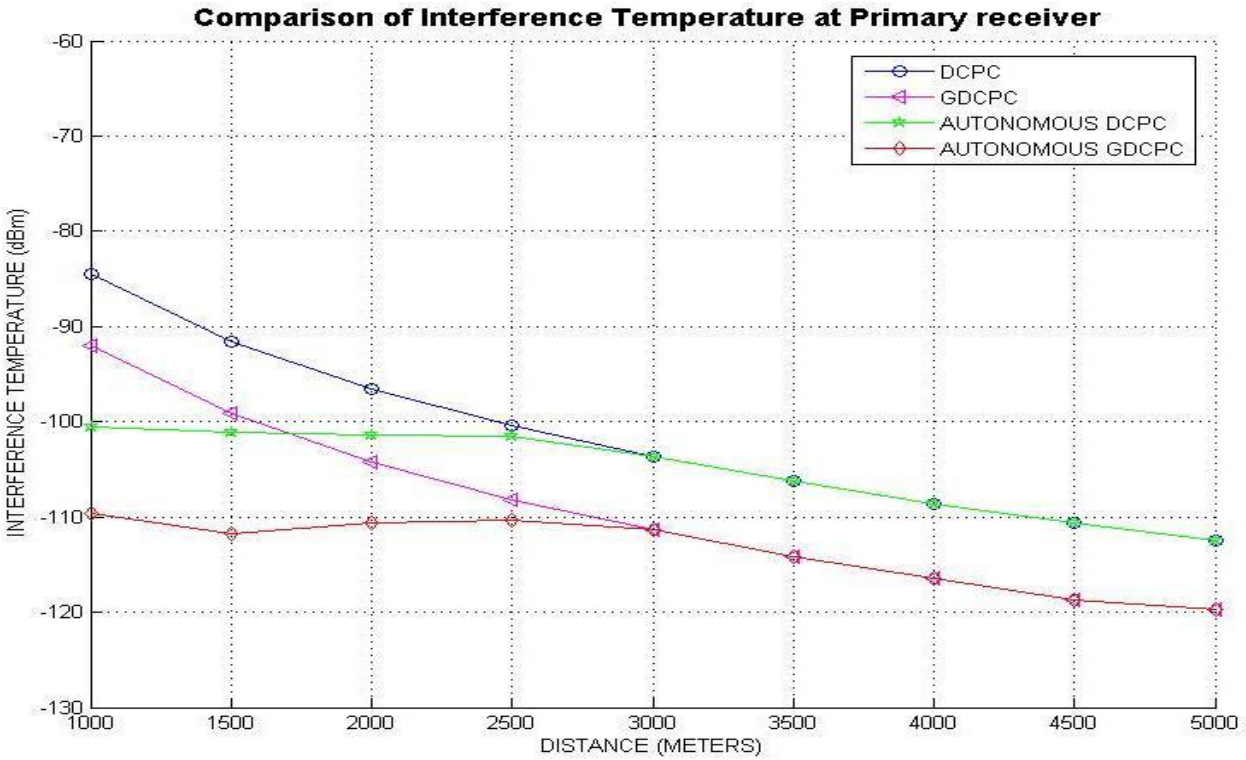
$$\overline{P}_i = \min\left\{\overline{P}, \min\left\{P_{SU}^{\max}, \frac{\xi_{TV}^{thr}}{G_{TV,i}N}\right\}\right\}$$

Simulation Parameters

PARAMETERS	VALUES
Number of CRUsers	50
Transmission range of CR Users	500m
Maximum transmit power	100mW
Transmit power of TV station P_{TV}	100kW
TV Transmission Range	70km
Receiver noise power N_o	10^{-11}mW
QoS of license user:	-100dBm
QoS of CR user:	3dB
Path loss exponent of TV user	3
Path loss exponent of CR users	4

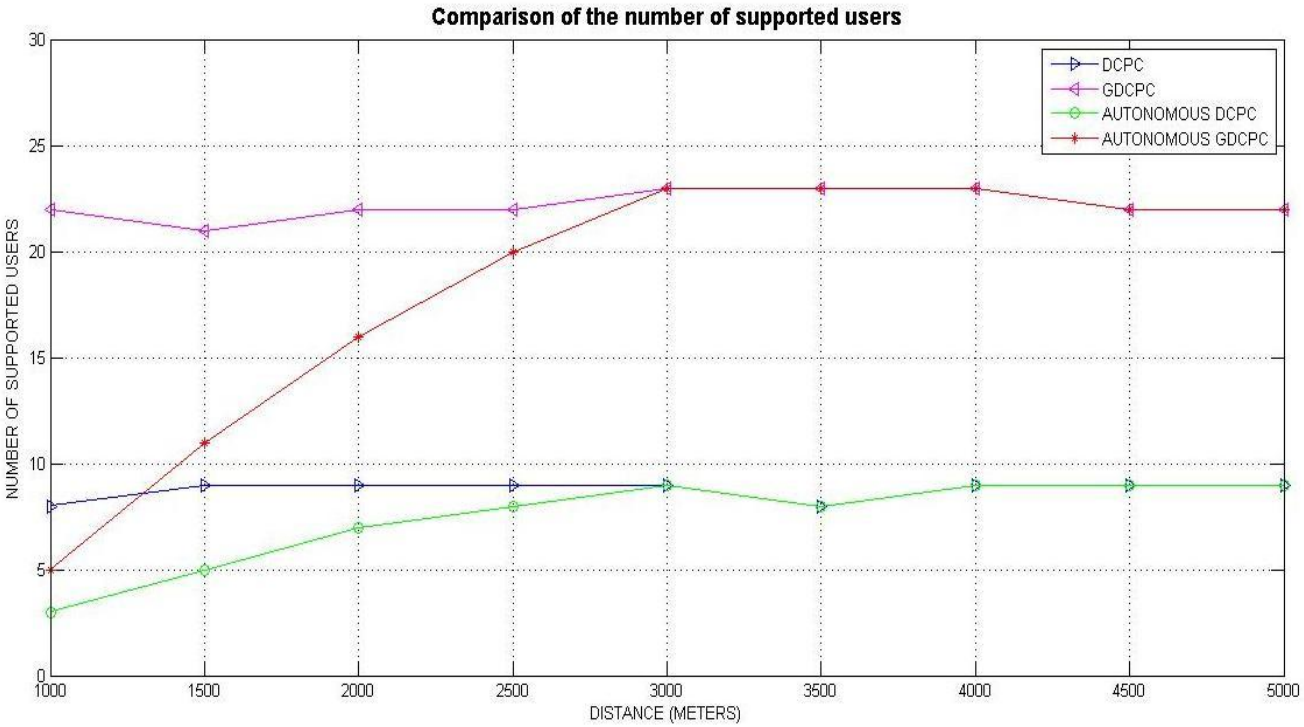
Simulation Results -DPC algorithms

Interference Temperature of PU Vs Distance



Inference: Longer the distance, lesser is the interference

Comparison of number of Supported users- DPC algorithms



Inference: As distance increases, CR users scarcely affect the primary users. Hence autonomous system equals conventional system.

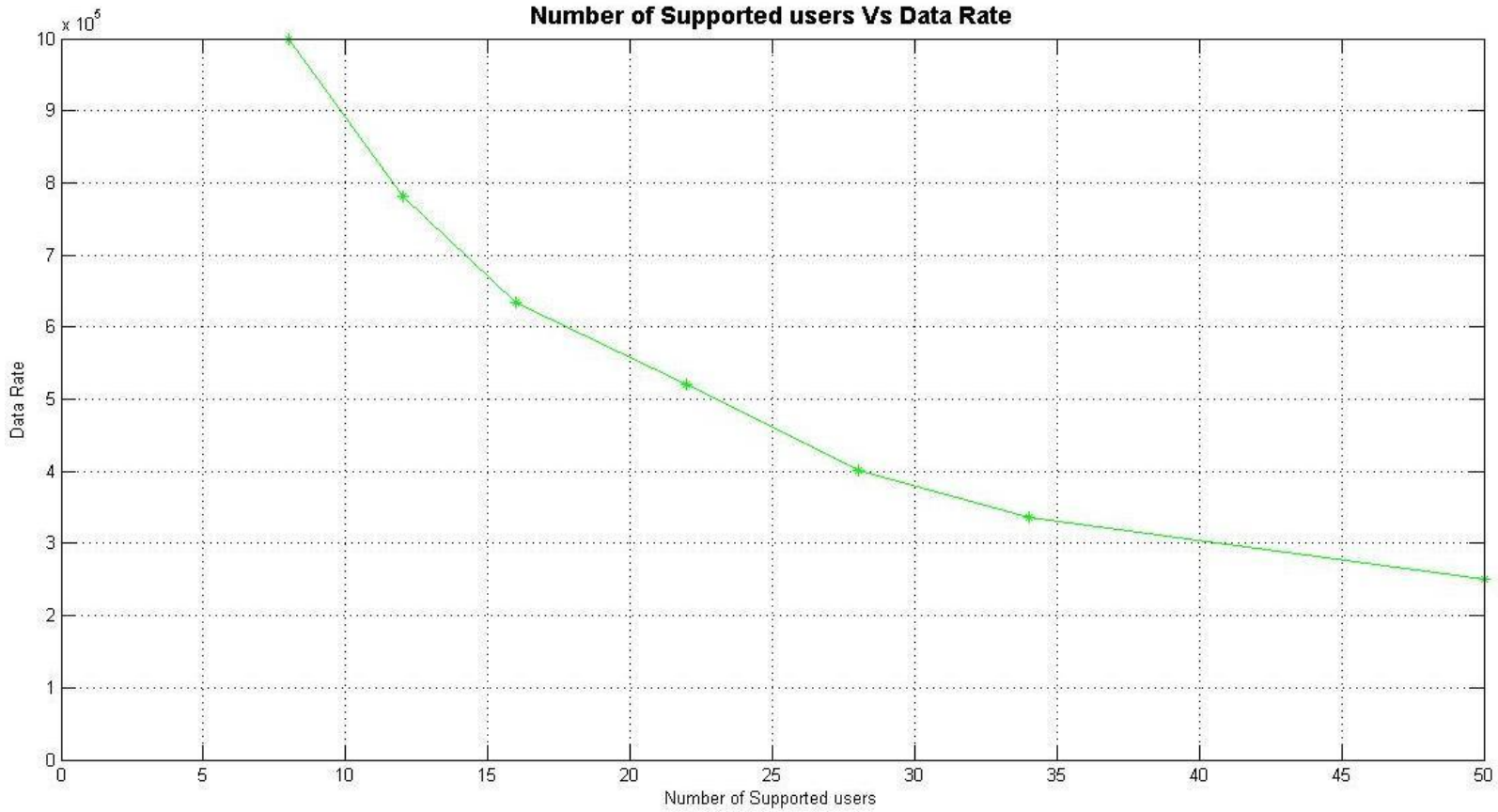
Proposed Algorithm

- In all the above discussed DPC algorithms, the transmission rate is maintained constant
- In the proposed joint rate and power control approach, the transmission rate of the CR user is varied.
- If the channel is in bad state and QoS constraints are not satisfied, the transmission rate is reduced and power is recalculated using DPC algorithm.
- By this way more number of users can be supported in the system on satisfying QoS constraints.
- The problem is further extended to provide specific minimum data rate to each user.

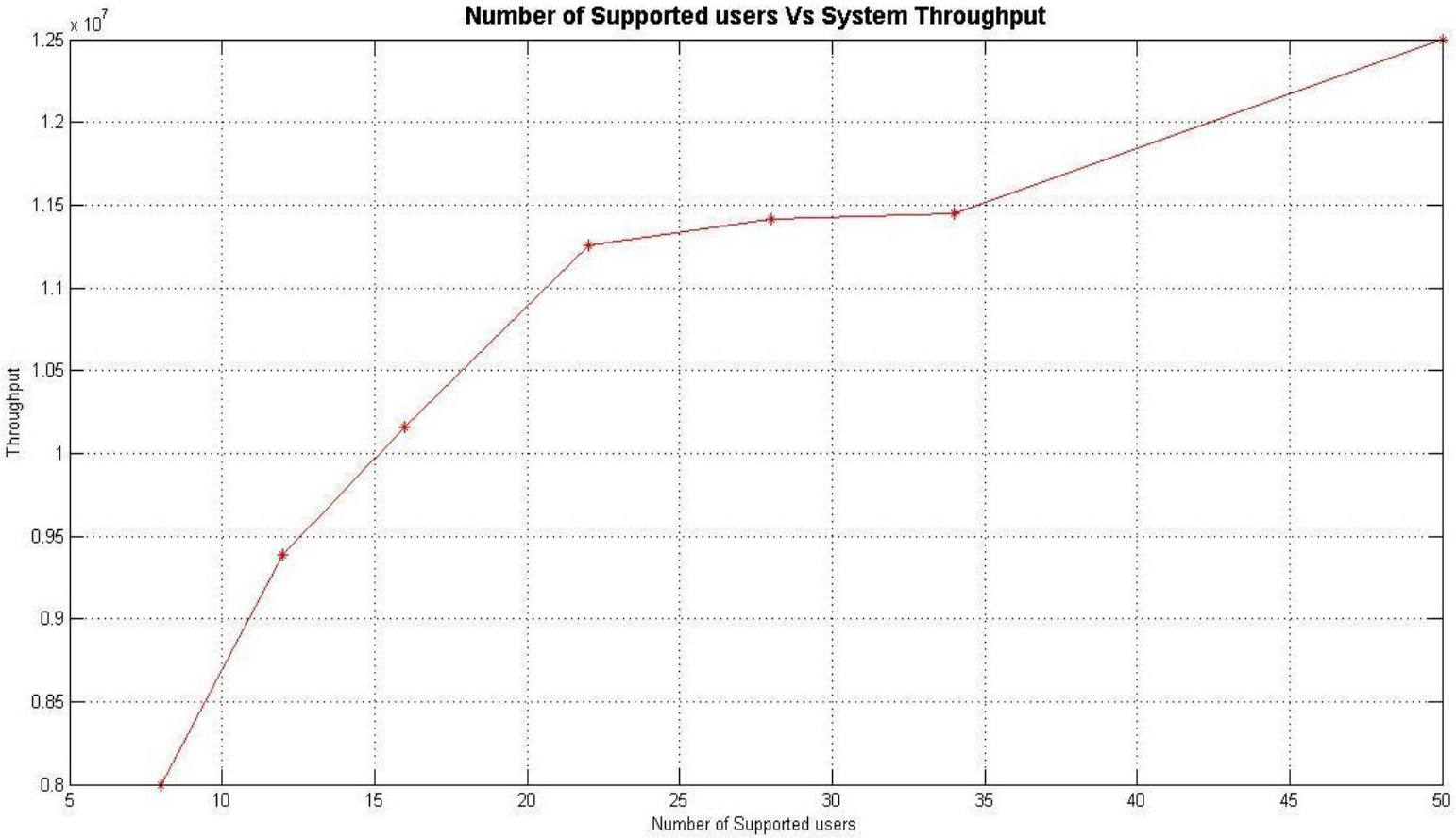
Results from proposed algorithm

SCENARIO	MEAN DATA RATE	NUMBER OF SUPPORTED USERS	THROUGHPUT
No rate control (Transmission at maximum data rate)	1Mbps	8	8Mbps
Rate control with lower rate constraint of 700Kbps	0.782Mbps	12	9.384Mbps
Rate control with lower rate constraint of 500Kbps	0.635Mbps	16	10.16Mbps
Rate control with lower rate constraint of 300Kbps	0.511Mbps	22	11.242Mbps
Rate control with lower rate constraint of 200Kbps	0.407Mbps	28	11.396Mbps
Rate control with lower rate constraint of 100Kbps	0.336Mbps	34	11.424Mbps
Rate control without lower rate constraint	0.250Mbps	50	12.5Mbps

Simulation Results - Proposed Joint Rate and Power control Algorithm



Comparison of Number of Supported users with System Throughput



Conclusion

- DPC algorithms, by its simple iterative convergence helps in designing a simpler system when compared to the centralised approach
- By adding additional constraint to the conventional DPC algorithm, the QoS of both PU and the CR users are simultaneously satisfied
- The proposed algorithm enables provision of different data rate to the CR users.
- By using the proposed approach, the overall throughput of the system is increased and also more number of users can be supported in the system.

Future Work

- An optimisation problem can be framed and an optimised solution for the joint power and rate control in the CR network can be derived
- The efficiency of the CR transmission can be increased, if the power and rate control techniques can be combined with the modern antenna beamforming techniques
- Security issues related to the CR transmission can be addressed
- The proposed idea can be extended to infrastructure based cellular network or a femto cell network while using other licensed spectrum like radio or mobile spectrum instead of TV transmission system

THANK YOU!