Cognition, Competition, Coordination and Cooperation: Insight into the 4C Behaviours in Next Generation Wireless Networks

Prof. Zhaoyang Zhang
Institute of Information and Communication Engineering, Zhejiang University
TEL&FAX: ***+86-571-87952060***
EMAIL: ***ning_ming@zju.edu.cn***

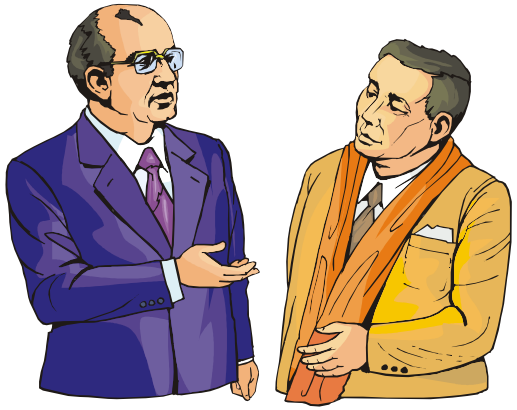
Agenda

- Introduction
- Insight into the 4C behaviours in next generation wireless networks
- Efficient protocol design in 4C-based wireless networks
- Conclusion

Introduction

- ***Competition*** always exists in wireless networks, for users have to compete for limited channel resources including time slot, subcarriers and transmitting power, etc.

- Proper ***coordination***, either centralized or distributed, should be employed to guide all the users to share the resources orderly and efficiently.
- The ***coordinator*** helps signal the channel occupations, and resolve possible channel collisions, so as to maintain a stable system operation.

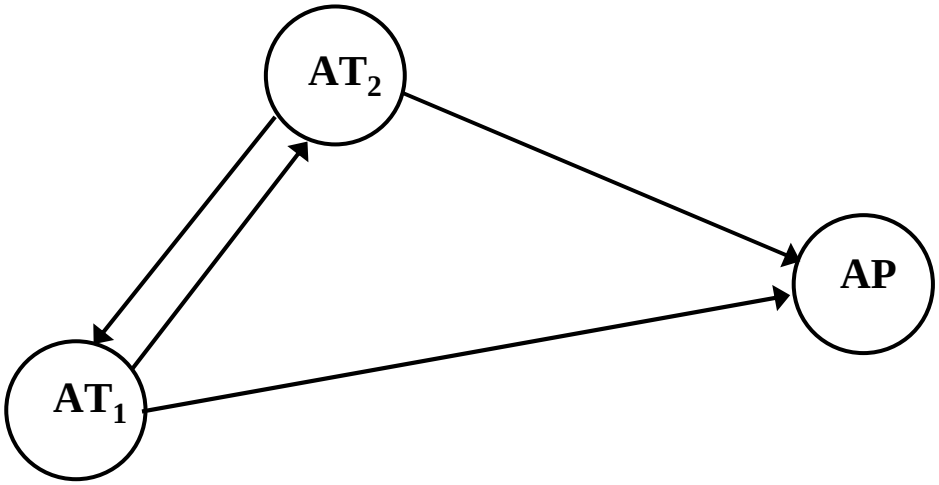


Introduction

- In traditional wireless networks:
  - ***coordination*** acts in a basis that all the users are ***egoistic*** and ***competitive***.
  - it mainly aims to regulate the ***competition*** among users.
- In next generation networks:
  - the users tend to be ***altruistic*** and ***cooperative***. Each user help others transmit information via certain kind of user ***cooperation***, thus enables all the users to share radio resources in a cooperative manner.
  - here ***coordination*** mainly aims to facilitate ***cooperation*** among users.

Introduction

- A typical user ***cooperation*** scenario: ***cooperative relay***
  - Each user cooperatively relay the information for other users in complement to their direct transmission link to the destination.
  - Greatly improves the transmission reliability and power efficiency.

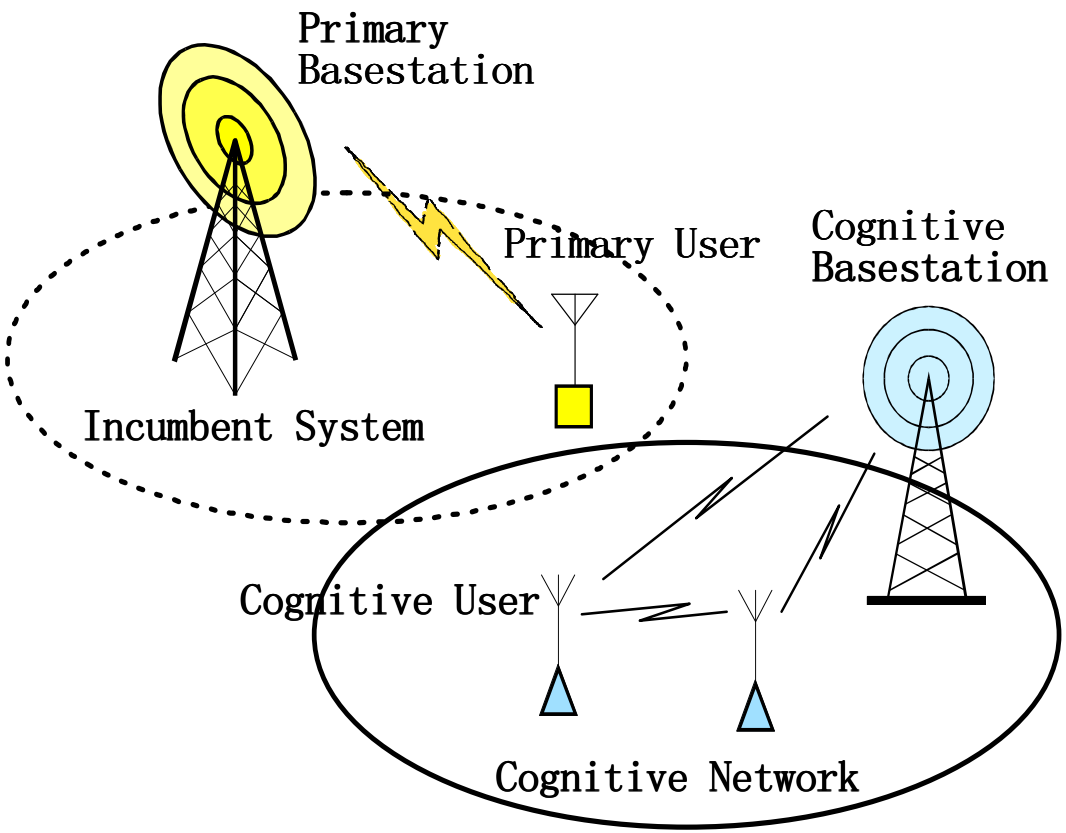


Introduction

- To make full use of the limited radio resources, each user will automatically ***sense*** the dynamic radio environment before accessing any resource.
- ***Intra-network sensing*** leads to improved ***coordination*** among users, like CSMA/CA used in IEEE802.11 WLAN;
- ***Inter-network sensing*** in multi-radio environment leads to the ***cognition*** of incumbent systems and subsequent dynamic resource sharing with them.
- ***Cognition*** enables the users to be:
  - Ambient-aware
  - Resource-aware
  - Proactive

Introduction

- A typical cognitive network:
  - Dynamically shares spectrum with the incumbent system via spectrum sensing
  - The cognitive user should have little or limited interference to the primary user sharing the same spectrum



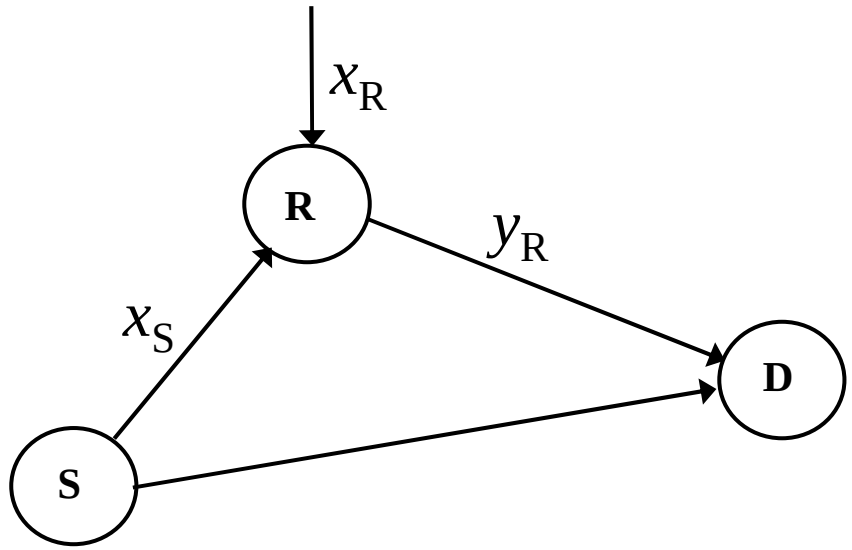
Insight into the 4C behaviours in next generation wireless networks

- ***Competition*** and ***cooperation*** are just two different ways to share the limited radio resources among users, they both can be regarded as ***radio resource access*** processes from the link layer point of view, only the former is competitive while the latter is cooperative.
- ***Cognition*** is the way of dynamically sharing radio resources among users or between multi-radio systems, it can be regarded as ***radio resource exploring*** process from the link layer point of view.
- ***Coordination*** is the set of signals or actions taking place among users, before or after competition, cooperation and cognition, in order to regulate and facilitate these behaviours.

Insight into the 4C behaviours in next generation wireless networks

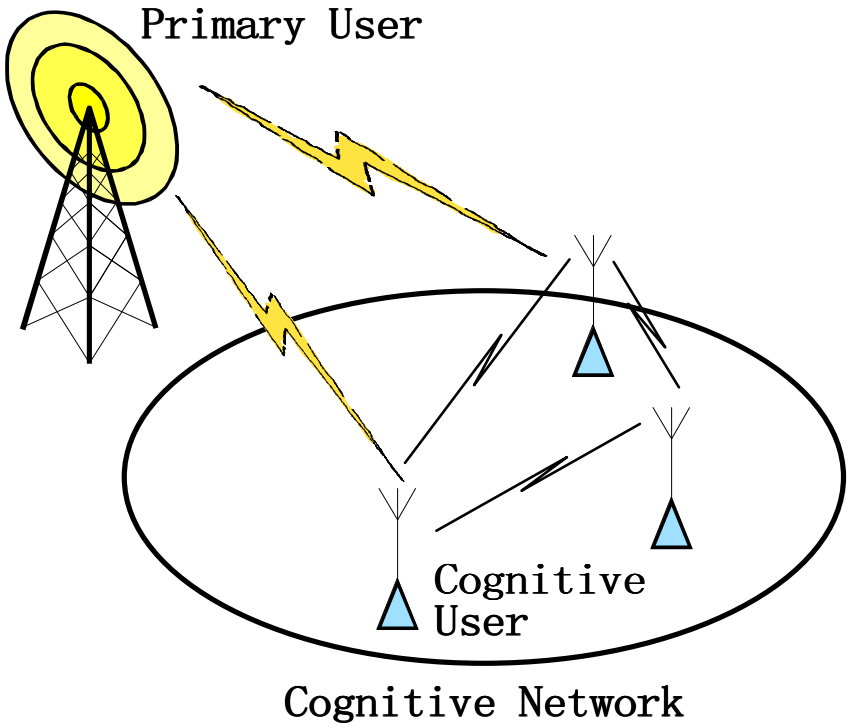
- Tradeoff between ***competition*** and ***cooperation***
  - Competition will arise in case that the source and relay node both have information to transmit;
  - The relay node can choose to transmit its own information only (***full competition***), or to transmit the source's information only (***full cooperation***), or to tradeoff between them using the limited radio resource.

$$y_R = f\,(x_S, x_R \mid Resource = const.)$$



Insight into the 4C behaviours in next generation wireless networks

- ***Cognition*** based on ***cooperation***: ***cooperative sensing***
  - Users in a cognitive network jointly sense the signal from primary user via cooperative relay.
  - Greatly improves the reliability of sensing.

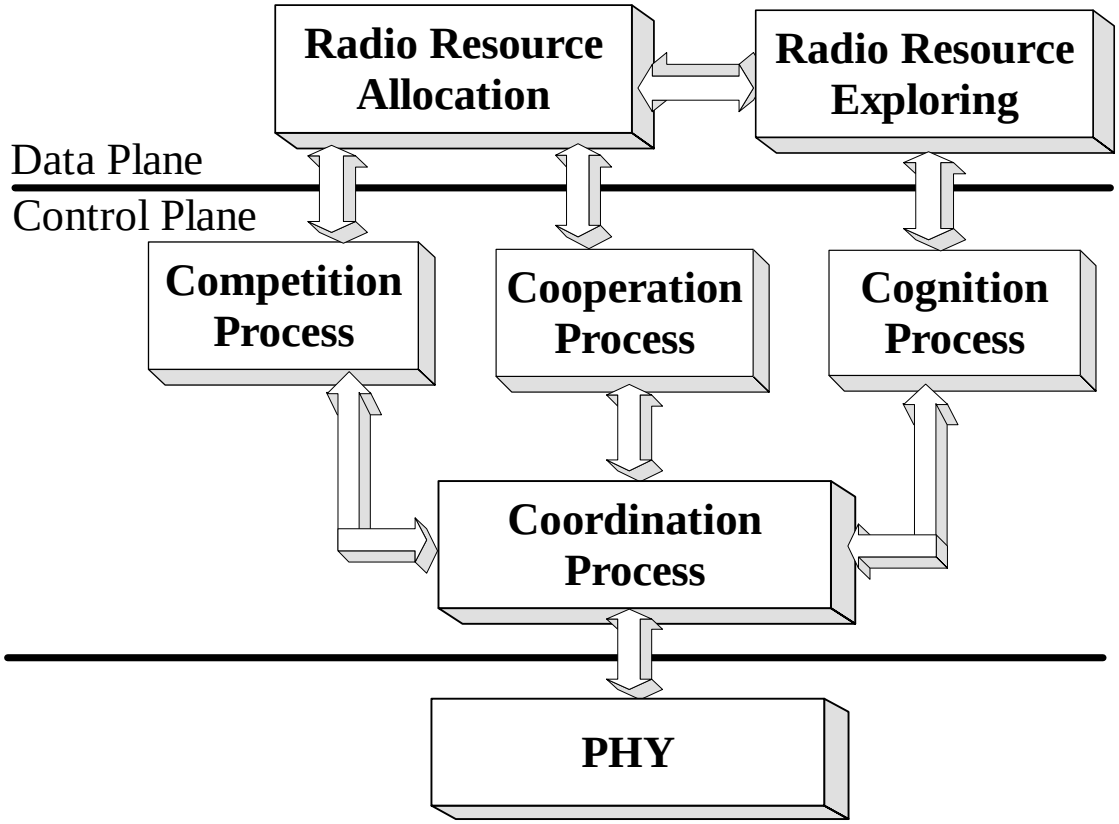


Insight into the 4C behaviours in next generation wireless networks

- ***Competition*** based on ***intra-network cognition***
  - Each user senses the
    - average number of active users,
    - average duration of channel occupation,
    - average interferences from other concurrent links, etc.
  - Then adaptively adjusts its
    - backoff window,
    - packet length,
    - *MCS*s and transmitting power, correspondingly.
  - Thus to improve
    - Radio resource utilization,
    - Throughput and delay performances.

Efficient protocol design in 4C-based wireless networks

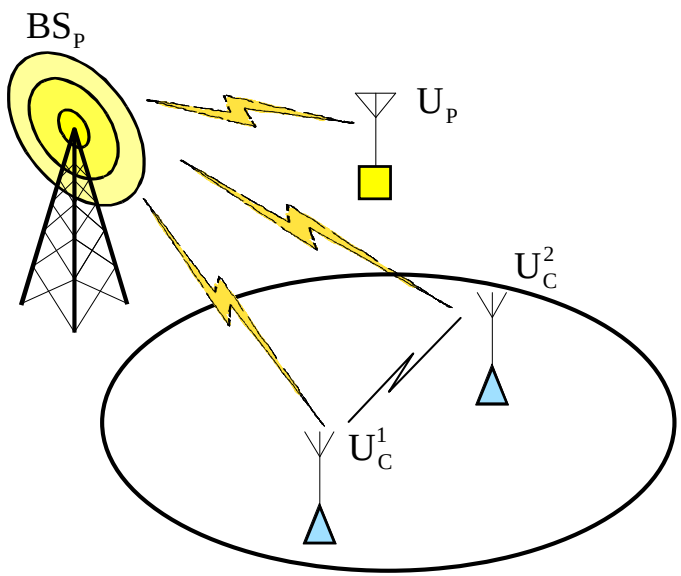
- Hierarchy of the lower layer protocol for a 4C-based wireless networks

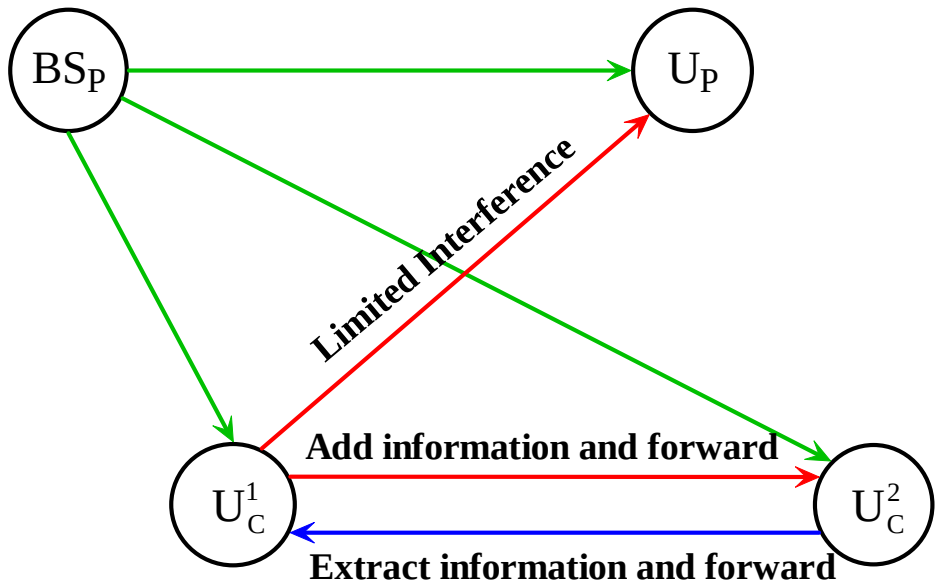


Efficient protocol design in 4C-based wireless networks

Cognition Process

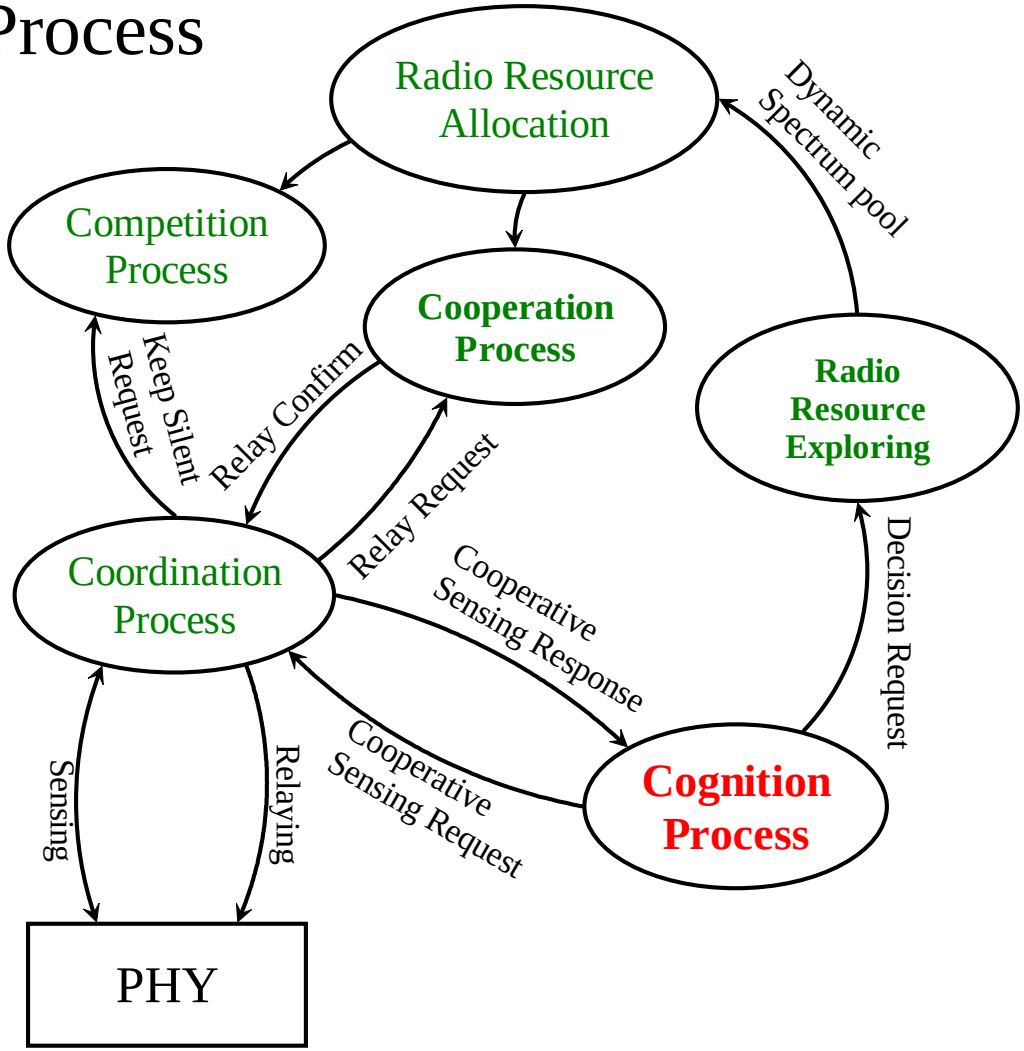
- **In each cognition cycle, the sensing user Uc1 will receive 3 successive segments of primary signal:**
  - First segment received by both Uc1 and Uc2 at start;
  - Second segment received by Uc2 when receiving signal forwarded by Uc1 in time slot 2;
  - Final segment received by Uc1 itself when receiving signals forwarded by Uc2 in slot 3;
- **Then Uc1 can do the joint sensing using the above 3 segments.**





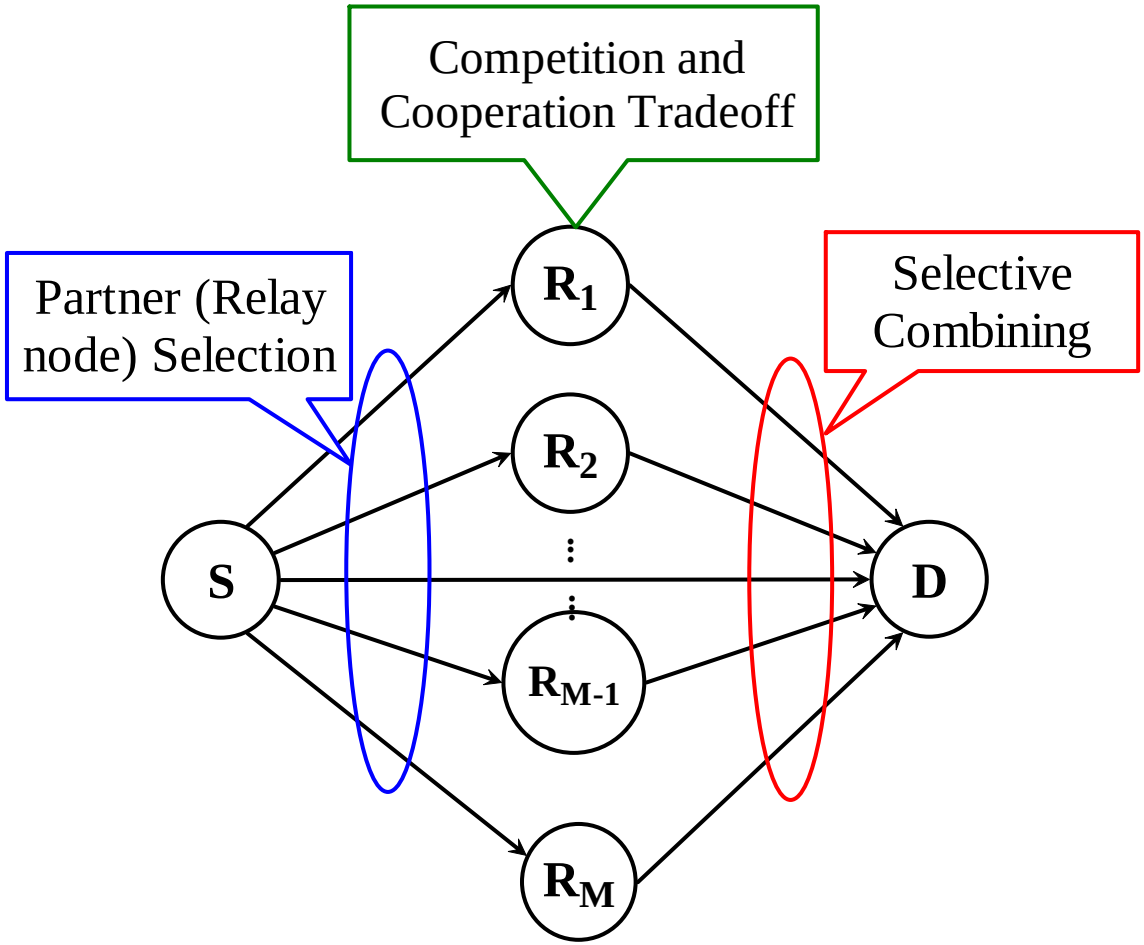
Efficient protocol design in 4C-based wireless networks

- Cognition Process



Efficient protocol design in 4C-based wireless networks

- Cooperation Process



Efficient protocol design in 4C-based wireless networks

- Radio resource access protocol design considerations
  - As for Cognition:
    - Interference Avoidance Based Protocols: Cognitive OFDMA
    - Interference Limiting Based Protocols: Interference Temperature Multiple Access (ITMA) .
  - As for Competition:
    - Interference Avoidance Based Protocols: CSMA/CA
    - Interference Averaging Based Protocols: CDMA
    - Interference Cancellation Based Protocols: Interleave Division Multiple Access (IDMA)
  - As for Cooperation:
    - Interference Utilizing Based Protocols: by increasing concurrent relaying of the same signal, to increase diversity
    - Delay-constrained Multi-link access Protocol
    - Multi-hop Power Control Protocol

Conclusion

- The presentation
  - introduced the 4C-behaviours in next generation wireless networks
  - gave our insight into the intrinsic virtues of the 4C-behaviours
  - discussed the efficient protocol design in 4C-based wireless networks
- It shows that
  - competition and cooperation are different ways of radio resource access, they should be tradeoff for optimal resource utilization
  - cognition is a way of radio resource exploring, it can be enhanced by user cooperation.
  - in a 4C-based network, the radio resource access protocol should be designed to avoid or limit both the intra-network and inter-network interferences.

Thanks !