Implementation and Evaluation of Distributed Control and Data Channel Coordination Algorithms for V2V Dynamic Spectrum Access

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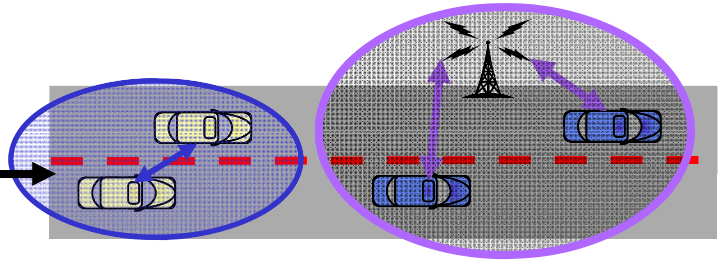
Background: Vehicular Networking

- Vehicular networking including vehicle-to-vehicle (V2V) communications is envisioned to enable numerous applications
- These applications have significant potential to increase…
  - <u>safety and convenience of transportation systems (non-safety)</u>
  - road traffic efficiency

Vehicle-to-vehicle (V2V) communication



Vehicular Networking

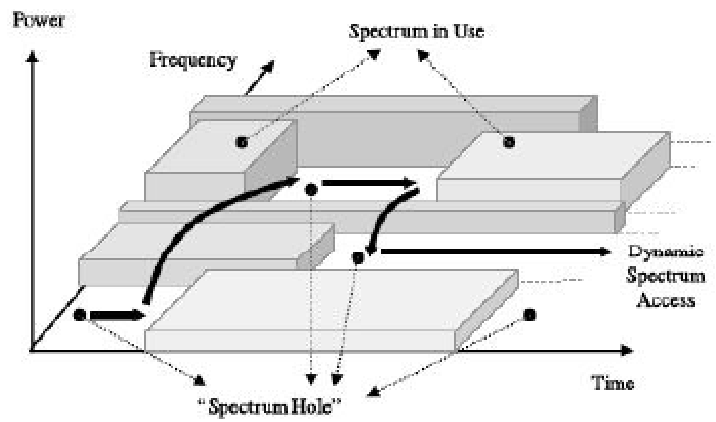
- Spectrum requirements of future vehicular networking applications are yet to be understood….
- With the proliferation of new vehicular applications, spectrum scarcity may soon be an inevitable reality for vehicular networks

=> How to solve the problem?

Dynamic Spectrum Access (DSA) technology

- We advocate the use of **dynamic spectrum access (DSA)/cognitive radio) technologies** in vehicular networks
  - In addition to the already assigned spectrum bands for Intelligent Transportation Systems (ITS) applications
- DSA technologies in a narrowly defined way..
  - can detect **spatial** and **temporal** “unused holes” in spectrum and allocate those unused portions to communicating entities dynamically on a secondary usage basis
  - While ensuring that the rights of the incumbent license holders (primary) are respected

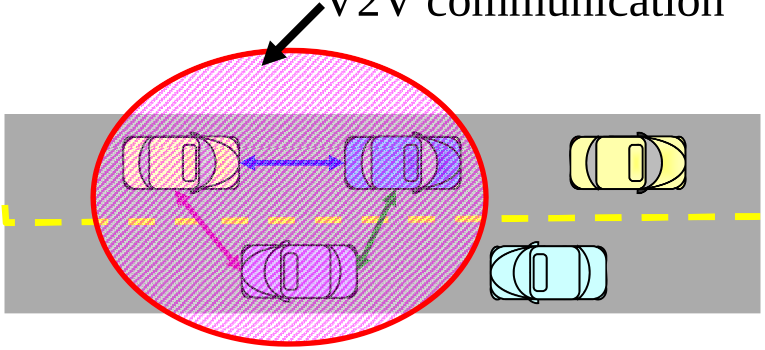
primary/secondary user model-based DSA



Concept of Dynamic Spectrum Access

DSA technologies in V2V communication

- In our previous works, the DSA technologies was applied to Vehicle-to-Vehicle (V2V) communications



- Advantages
  - Spectrum utilization is drastically increased (in DSA)
  - Deployment cost is decreased (in V2V)
- Disadvantages
  - There is **no infrastructure** (in V2V)
    - Centralized control is not appropriate => **Distributed control** is necessary
  - Nodes have **high mobility** and their density is relatively different (in V2V)
    - Participation/secession occur frequently => **Self-organization** is difficult
  - Neighboring two nodes have to select a same channel simultaneously from a **broad range of frequency** for a communication setup (in DSA)
    - They need to select a channel from 400MHz to 6GHz
=> **Channel coordination** is extremely difficult

Our previous works

- Channel coordination in DSA network
  - Needs to scan **all** the communication channels (400MHz to 6GHz)
    - Scanning period becomes **larger than 10 seconds**
  - Needs to determine the communication parameters according to the utilization
    - Communication condition of sender and receiver **would not be synchronized**
- We developed a **distributed and autonomous dynamic spectrum coordination method** tailored for 1-hop V2V communications [1]
  - , which can establish a control channel reliably and quickly
- In [2], we proposed several **metrics for selecting data channel** by exploiting the information on spatial and temporal spectrum changes exchanged over the control channel established in [1]
  - Metrics take into account several factors (distance, data rate, vehicle velocities)

[1] K. Tsukamoto et. al.,, "**Distributed Channel Coordination in Cognitive Wireless Vehicle-to-Vehicle Communications (Invited Paper),"** Proc. of **WAVE2008**, CDROM, December 2008.
Available at http://www.ndrc.kyutech.ac.jp/research_file/20090605134544-1u.pdf
[2] K. Tsukamoto et. Al., "**On Spatially-Aware Channel Selection in Dynamic Spectrum Access Multi-hop Inter-Vehicle Communications (Invited Paper)**," IEEE VTC2009-fall, CD-ROM, September 2009.

Objective

- So far, we evaluated those methods **only via computer simulations** by injecting probabilistic primary user "appearances" (exponential distribution) on a road segment

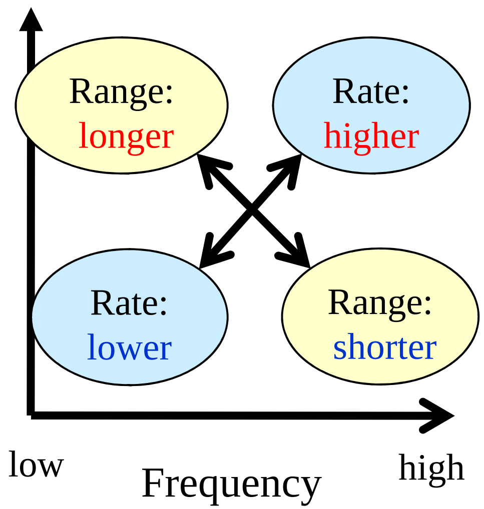
- Our objective is to show the **cyber-physical proof-of-concept lab implementation of the methods** in [1] and [2]
  - We develop lab prototype implementation by using the **GNU Radio** software radio platform with **USRP** hardware
  - Our implementation is an integration of **spectrum sensing** and **channel coordination functions** working on GNU Radio/USRP with emulation of primary user "appearances" based on actual TV white space measurement [4]
    - Spectrum sensing implementation is based on energy detection similar to [3]

=> We will mainly focus on the part of **channel coordination functions [1][2]**

[3] C. Lacatus, R. Vuyyuru, O. Altintas, D. Borota and I. Seskar, "**Evaluation Of Energy-Based Spectrum Sensing Algorithm for Vehicular Networks**," Proc. SDR'09 Technical Conference, Dec., 2009, Washington DC, USA.
[4] S. Pagadarai, A. Wyglinski and R. Vuyyuru, "**Characterization of Vacant UHF TV Channels for Vehicular Dynamic Spectrum Access**," Proc. IEEE VNC2009, Oct. 2009, Tokyo, Japan.

Distributed and autonomous control and data channel coordination (1)

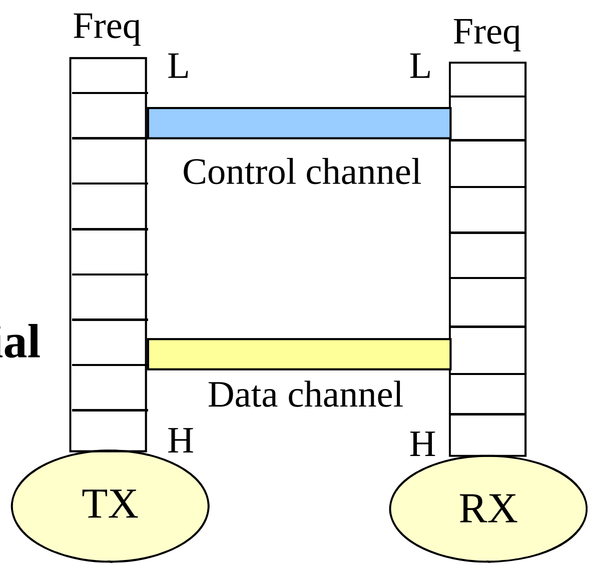
- In vehicular networking with DSA….
  - one can make use of the difference in characteristics of individual channels within a broad range of available radio frequencies
    - 1-hop communication range becomes **longer** as the frequency becomes lower
      - if the Tx power and modulation scheme are same
    - Higher freq. can provide **higher** data rate because relatively wider bands can be aggregated



  - Control information will require a **reliable** and sometimes longer-distance "**connectivity**" to be able to exchange small messages periodically
  - Requirements for application data exchange vary widely
    - Safety-related app. will need a **real-time, continuous**, but relatively **low rate**
    - Large file transfer app. will need **a reliable, high rate**, but possibly **non-real-time** communications

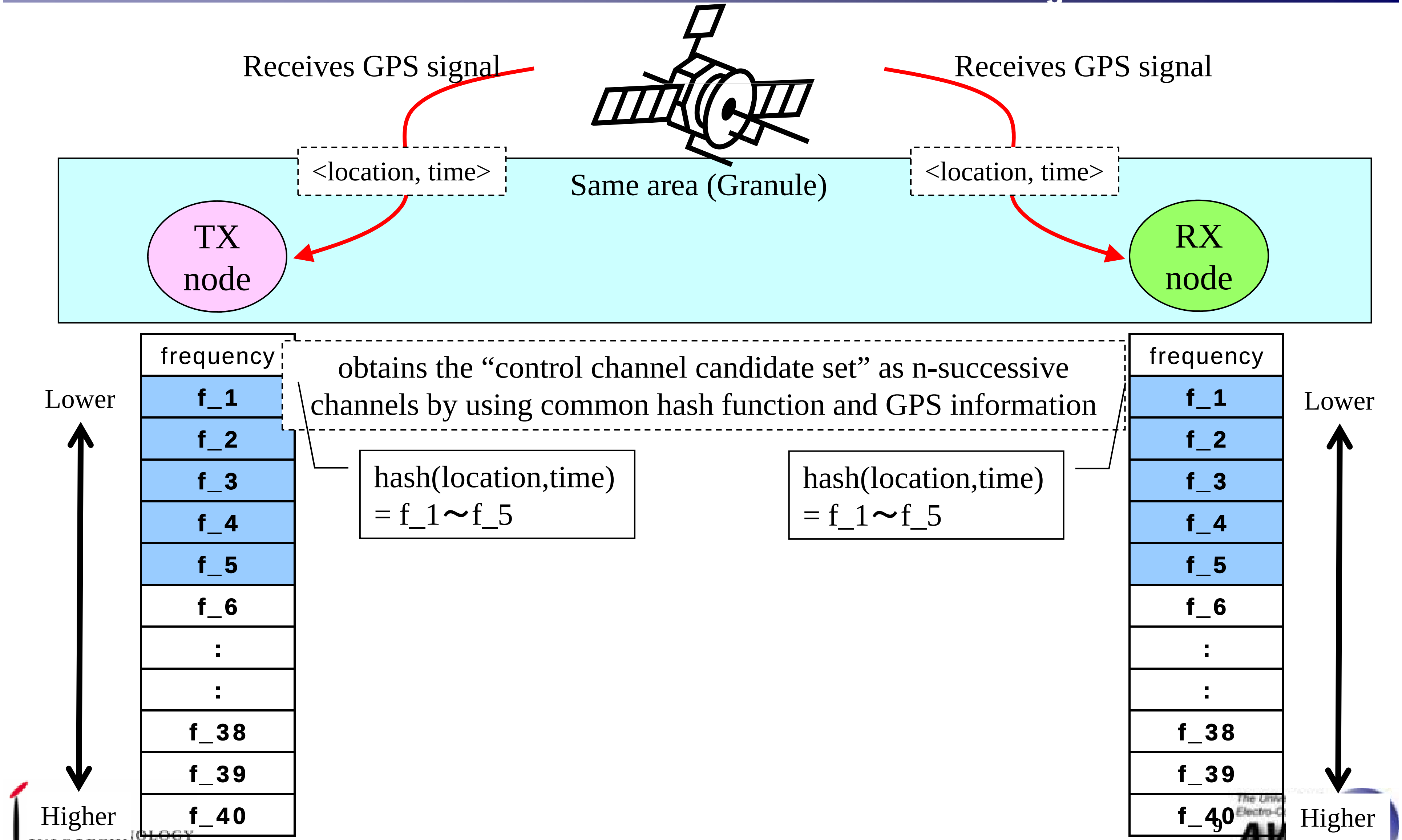
Distributed and autonomous control and data channel coordination (2)

- In our previous works, by considering those differences…
  - We separated the control channel(s) and the data channel(s)
    - Control channel is used for **periodical and reliable** exchange of control information
    - Data channel is used for **various types of application data** exchanges
- Detailed procedures
  - Vehicles initially agree on the control channel from within a **relatively narrow range of lower frequencies**
    => shortening the sensing period drastically
    - They make use of **each other's temporal and spatial proximity relationships (same area and location)**
  - Then, they decide on the data channels by negotiating over the control channel
    - Data channel is frequencies suitable for application requirements

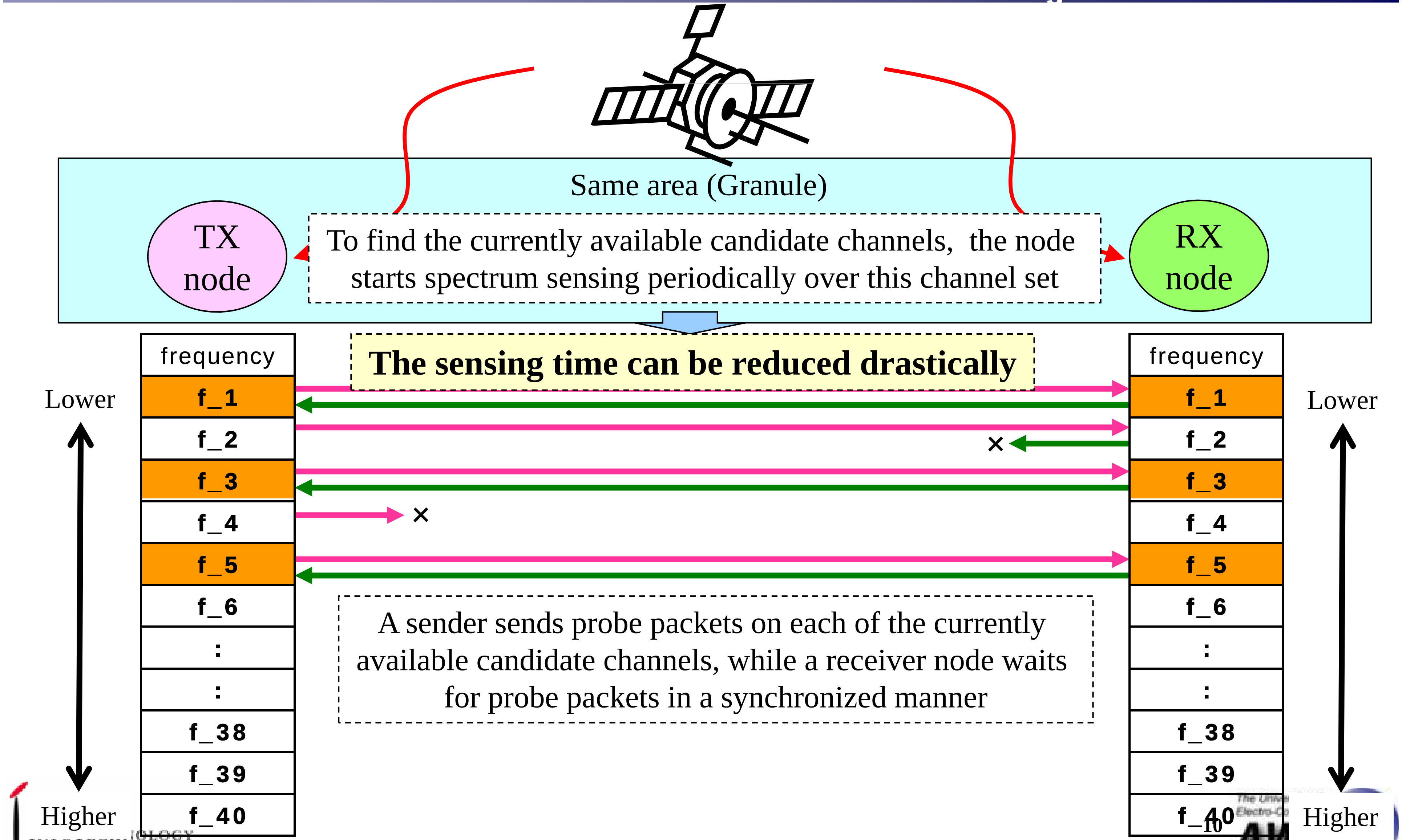


Concept of previous work

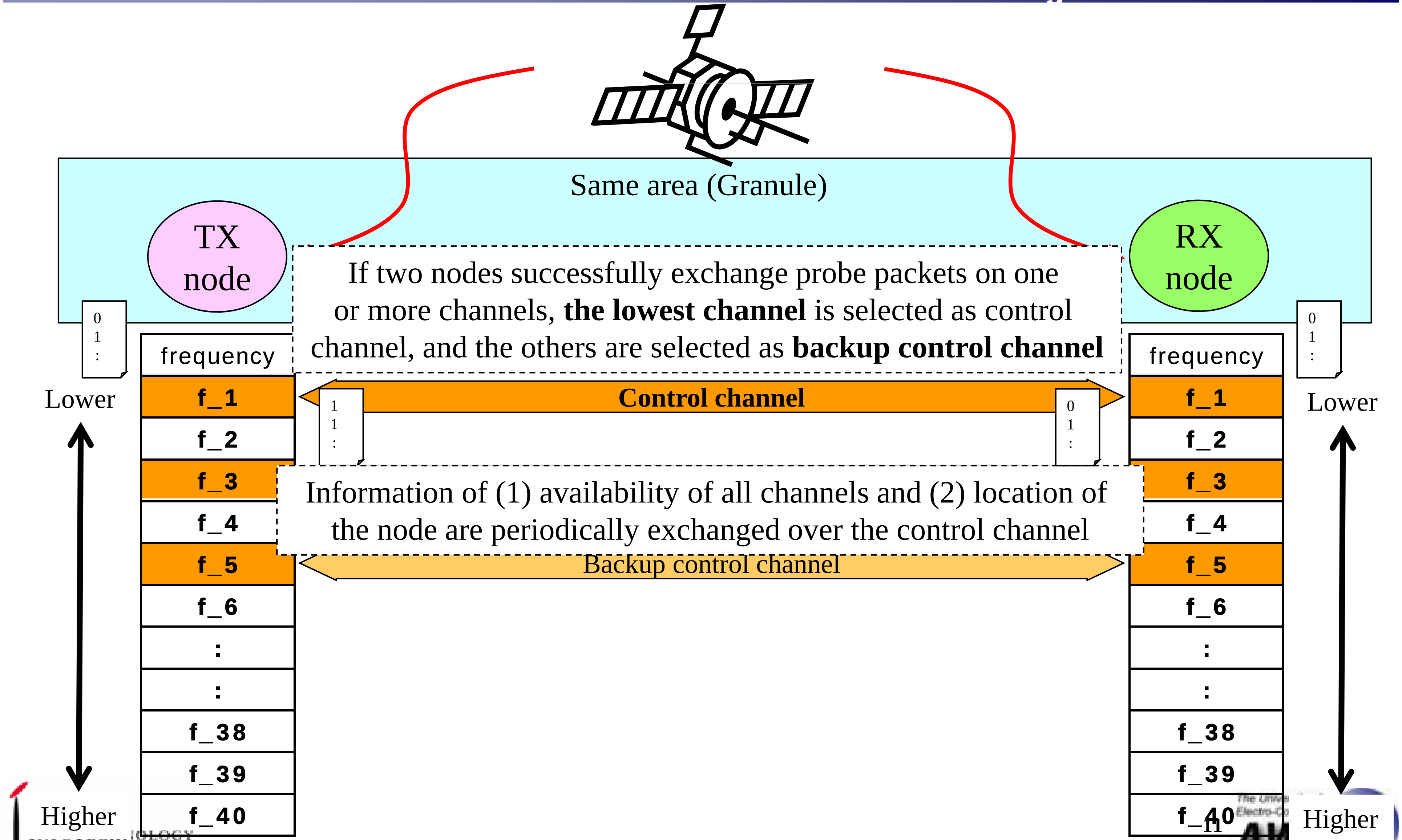
Proposed scheme (1): obtain the shared “n” channel



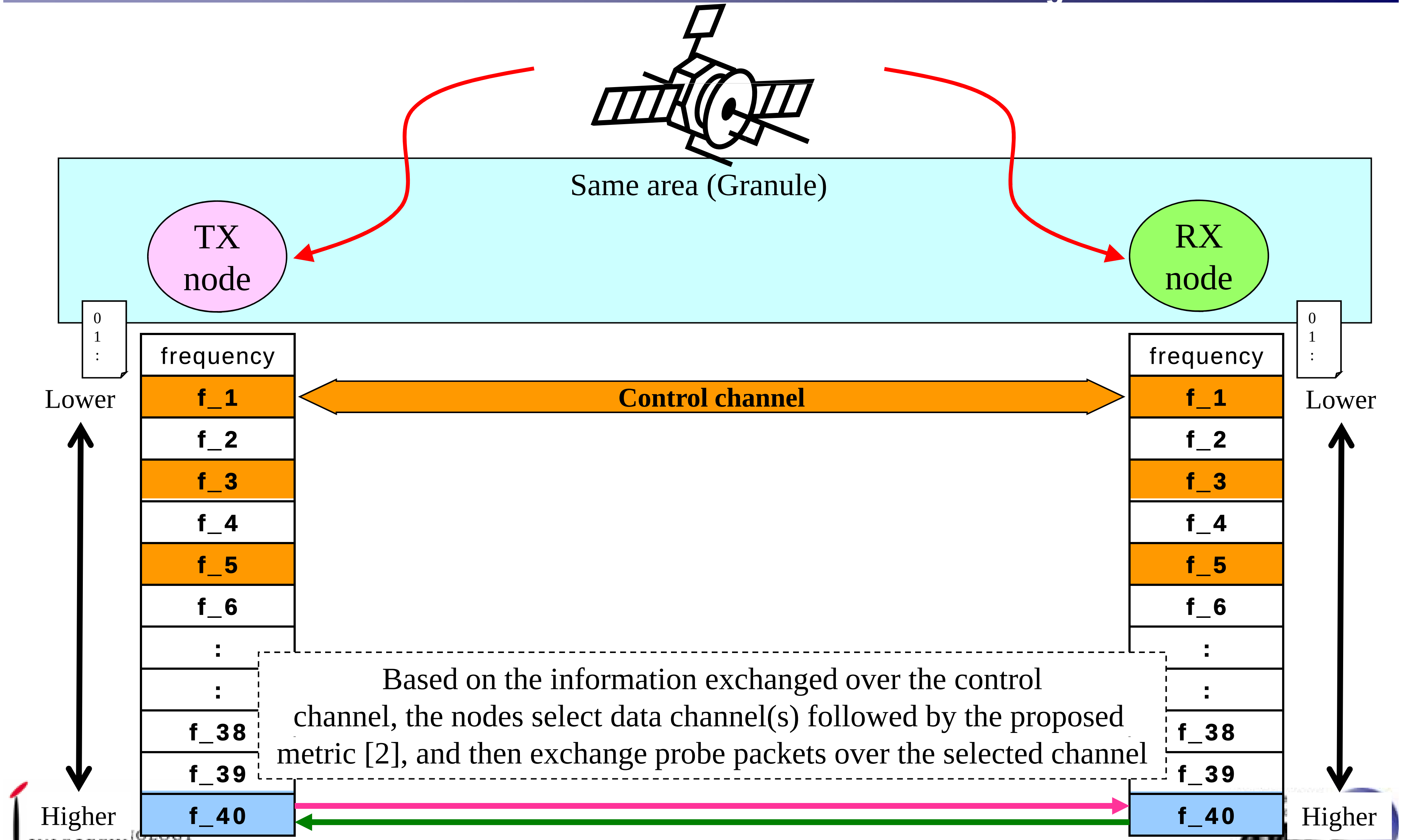
Proposed scheme (2): exchange of probe packets



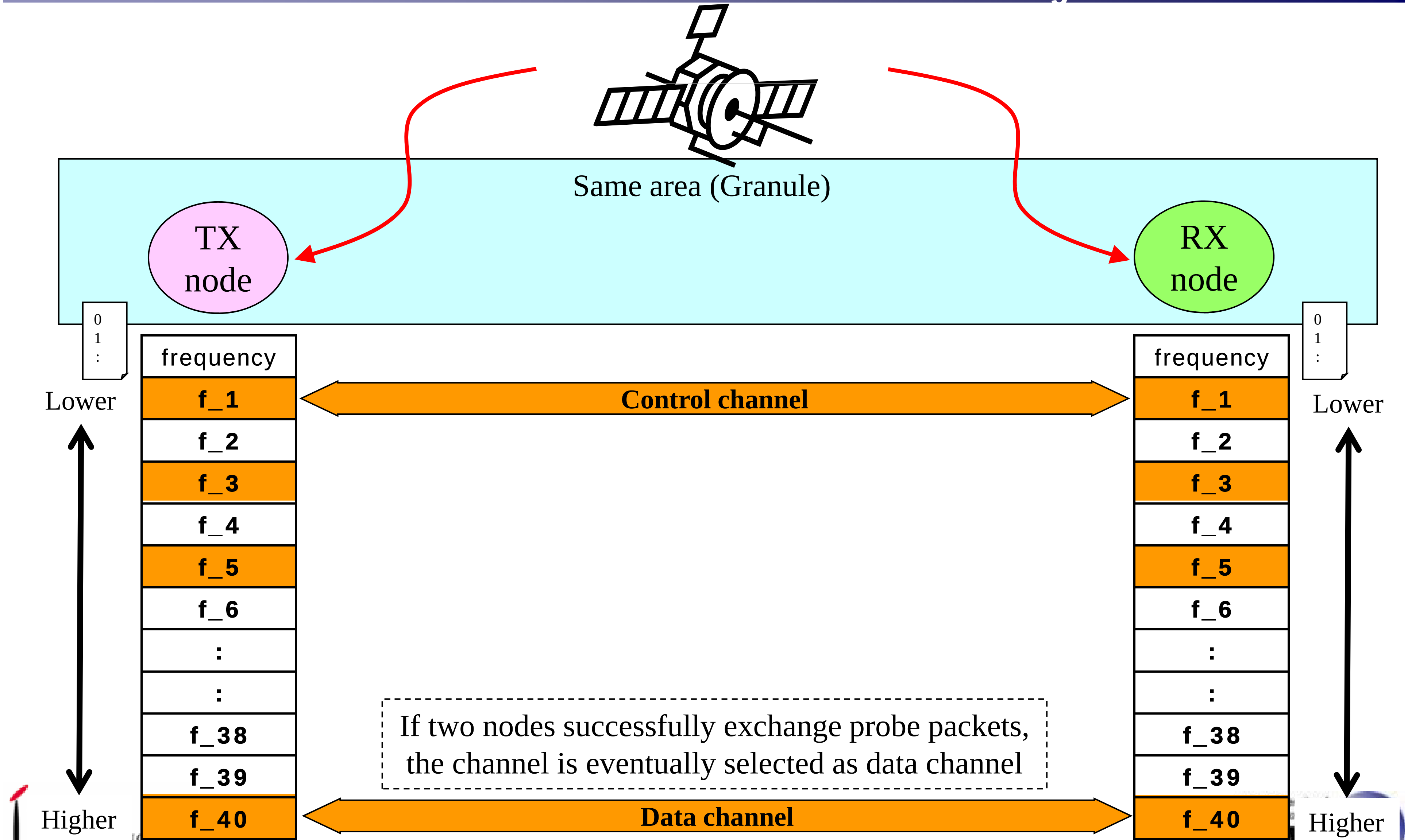
Proposed scheme (3): decision of control channel



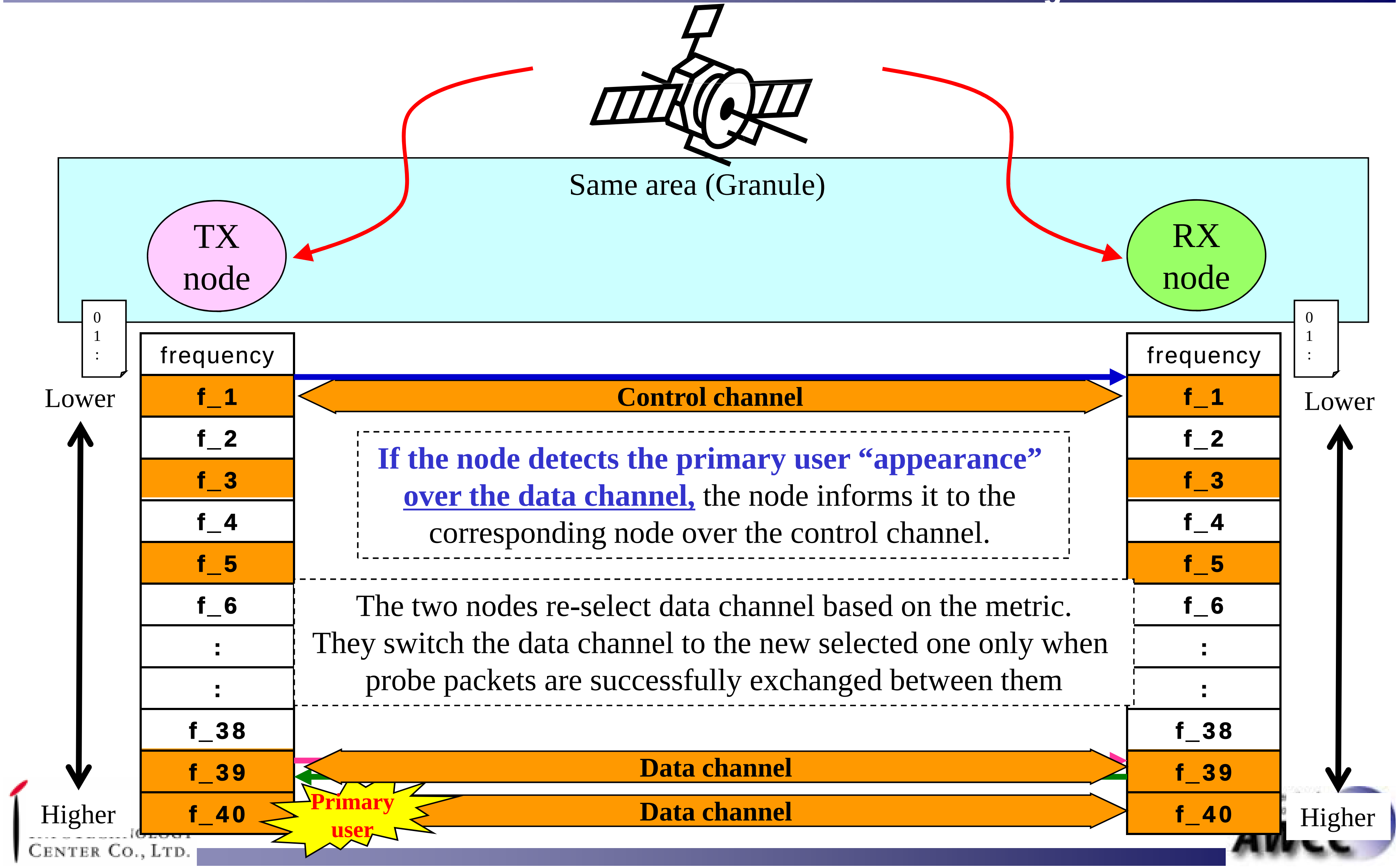
Proposed scheme (4): decision of data channel



Proposed scheme (5): decision of data channel



Proposed scheme (6): Detection of primary user

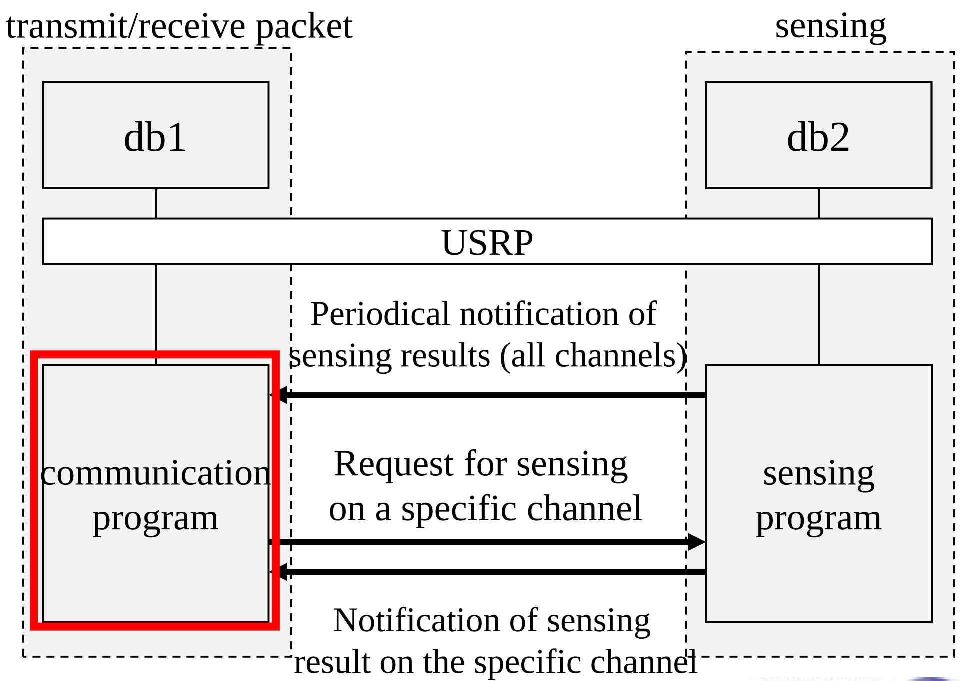


Lab prototype implementation details:

Integration of spectrum sensing and communication programs

- Sensing program
  - always performs sensing processes in parallel with the commu. program
  - periodically sends the sensing results of **all channels** to the commu. program
  - replies the sensing results of **one specific channel** whenever the commu. program asks to check whether the primary user exists or not

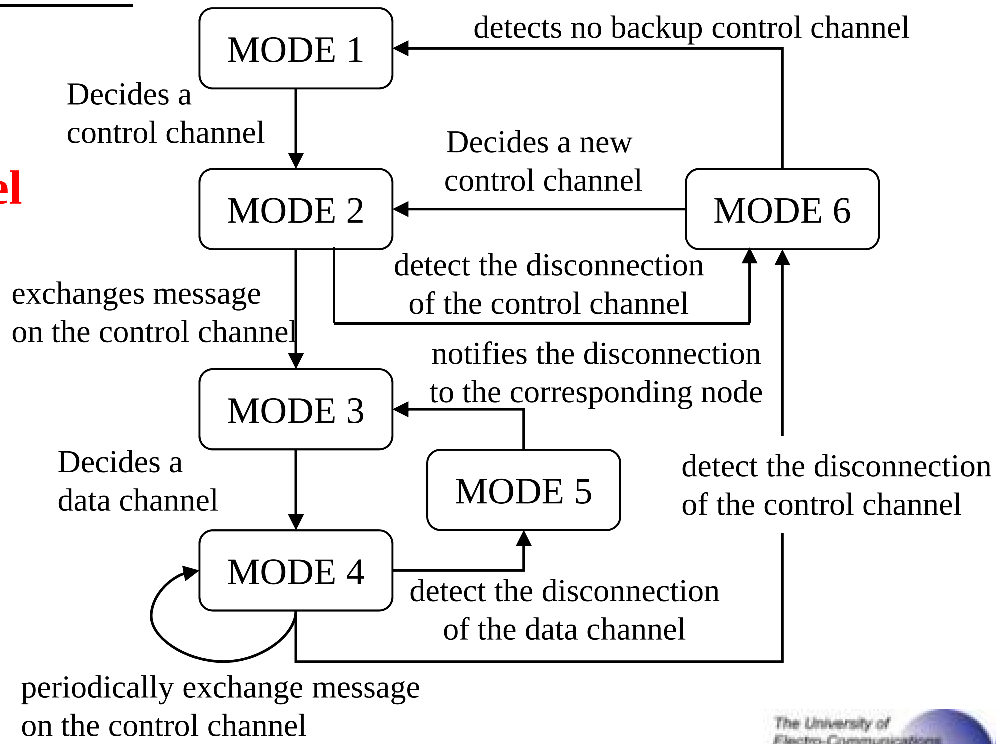
- We will focus on communication program and its implementation



Relationship between communication and sensing program

State transition in our implementation

- We divided distributed control channel coordination and data channel selection into 6 MODEs
  - MODE1: selects a control channel
  - MODE2: exchanges (1) <location, time> of each node and (2) a list of available channels over control channel
  - MODE3: select a data channel
    - Our implementation selects a channel with the **highest channel number**
  - MODE4: periodically exchange information over control channel
  - MODE5: informs the disconnection of data channel to the corresponding vehicle
  - MODE6: tries to establish a new control channel



Referring sample codes and functions

- We developed several communication programs by referring to ***benchmark_tx.py***, ***benchmark_rx.py***, and ***tunnel.py***
  - are provided as sample codes for GNU Radio/USRP (under /usr/share/gnuradio/example/digital)
  - **Benchmark_tx/rx.py** provide a function for packet send/receive, and **tunnel.py** provides a function for simple MAC protocol
  - ***"Main_loop"* function (**in a **tunnel.py)**
    - provides a block of sending process and determines the kind of information exchanged between the two nodes according to the MODE status
  - ***"Send_pkt"* function** (in a **benchmark_tx.py**)
    - can actually send a packet
  - ***"rx_callback"* function** (in a **benchmark_rx.py**)
    - defines a block of receiving processes
      - Shows the result of modulation function and packet sequence number
  - ***"set_center_freq"*** function (in a **generic_ursp.py**)
    - Can change the frequency dynamically without any interruption

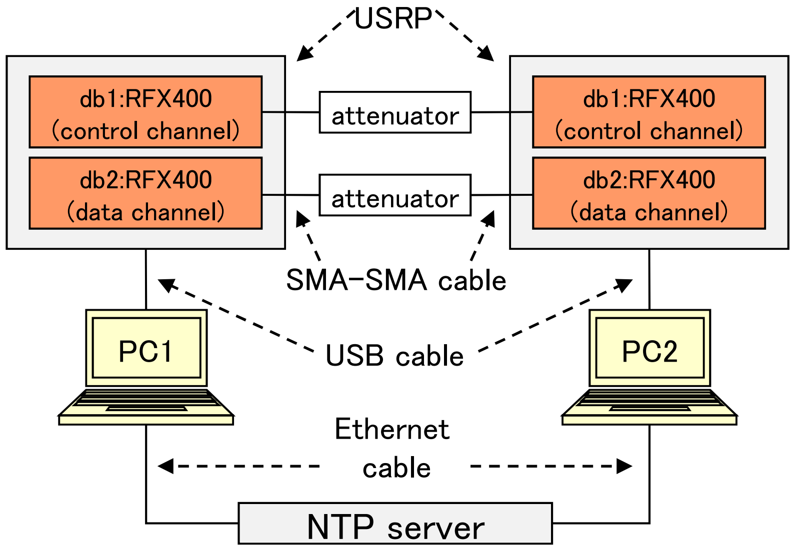
    -> **dynamic frequency change can be achieved** by utilizing this function

System components

- A USRP can have **only two** daughterboards
  - We conducted two experiments
    1. Control channel + spectrum sensing

    => Evaluation of sensing capability
    2. Control channel + Data channel

    => Evaluation of communication capability
- SMA-SMA cable (coaxial cable)
  - is used to emulate the wireless link between interfaces
- Two PCs are connected to a NTP server to achieve time synchronization between them
- Computational capability of node
  - GNU Radio 3.2
  - PC : Dell Studio 1737 Laptop
    - CPU:Intel Core 2 Duo T9600 2.80GHz
    - RAM:3GB
    - OS : Ubuntu 9.04



System components

Experimental environment

- We evaluate communication performance in a DSA environment emulated by using actual measurement results on TV channel [4]
  - [4] investigated the availability of vacant TV channel in 470-806 MHz frequency range along I-90 in the state of Massachusetts, USA
  - We set bandwidth of individual channels to 1 MHz
    - Is different than the actual TV channel bandwidth (6MHz)
- Assumptions
  - Tx power is fixed and velocities of the vehicles are stable at 40 Km/h
  - Primary user starts communication on the data channel only based on actual measurement results
    - never appears on the control channel

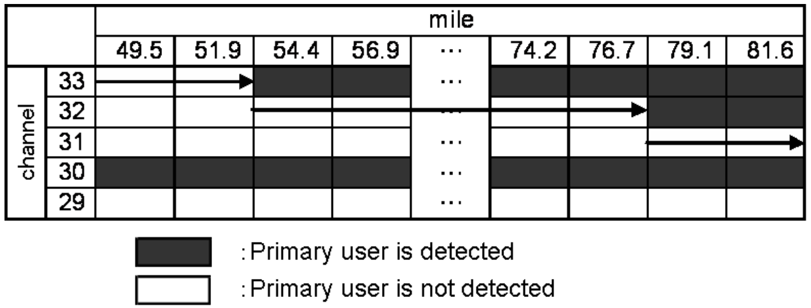
Experimental parameters

Daughterboard	RFX400
Num. of channels	5ch: Assumption of 29-33ch in VHF band on TV channel
Frequency range	428MHz-432MHz (1MHz bandwidth)
Control channel	29ch(fixed)
Measurement points	49.5mile-81.6mile (away from Boston city)

- Note that …
  - Our implementation selects a data channel **with the highest data rate** among all of available channels, i.e., **the highest channel ID**

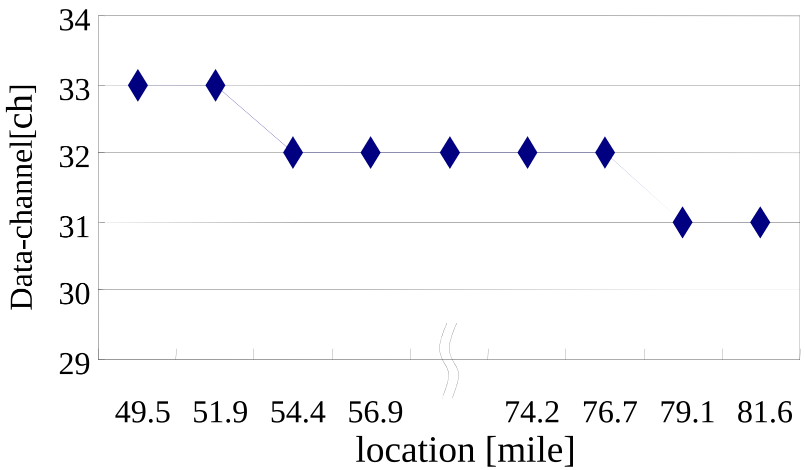
Experimental results

- Upper figure shows the utilization condition on TV channel band at several points extracted from results in [4]
  - Black boxes : **Existence of primary user**
    White boxes: **An available channel**
  - -> **Boxes along an arrow** represent the appropriate channel, (the highest channel ID among all available channels)



Measurement results of TV channels [4]

- Our prototype system…
  1. Selects on channel ID:33 until mile 51.9
  2. Detects the primary signal on ID:33 at 54.4 mile point, and changes the data channel to channel ID:32
  3. Similarly, the data channel is changed to channel ID:31 after the detection of primary user on channel ID:32 at 79.1 mile point



Change of the selected data channel

Our system can dynamically switch the data channel to an appropriate one as a result of message exchange over the control channel

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Conclusion

- We presented a **cyber-physical proof-of-concept lab implementation** of the our previous method
- We described a lab prototype implementation using **the GNU Radio/USRP platform**
  - is an integration of **spectrum sensing** and **channel coordination functions** working with emulation of primary user "appearance" based on actual TV white space measurement
- Current hardware limitations force our implementation to work either with "recorded/emulated" primary user activity
  - One USRP only have 2 daughterboards
  - Ideal implementation would consist of **three** daughter boards
    - for sensing, control, and data channels

•Our system is being transported onto USRP2
•We intend to carry out the field tests over vacant TV channels in a rather isolated geographical area in Japan
•We are presently working towards a couple of regulatory permissions

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