Symbiotic Radio: Enabling Mutualistic Spectrum Sharing for Wireless Communications

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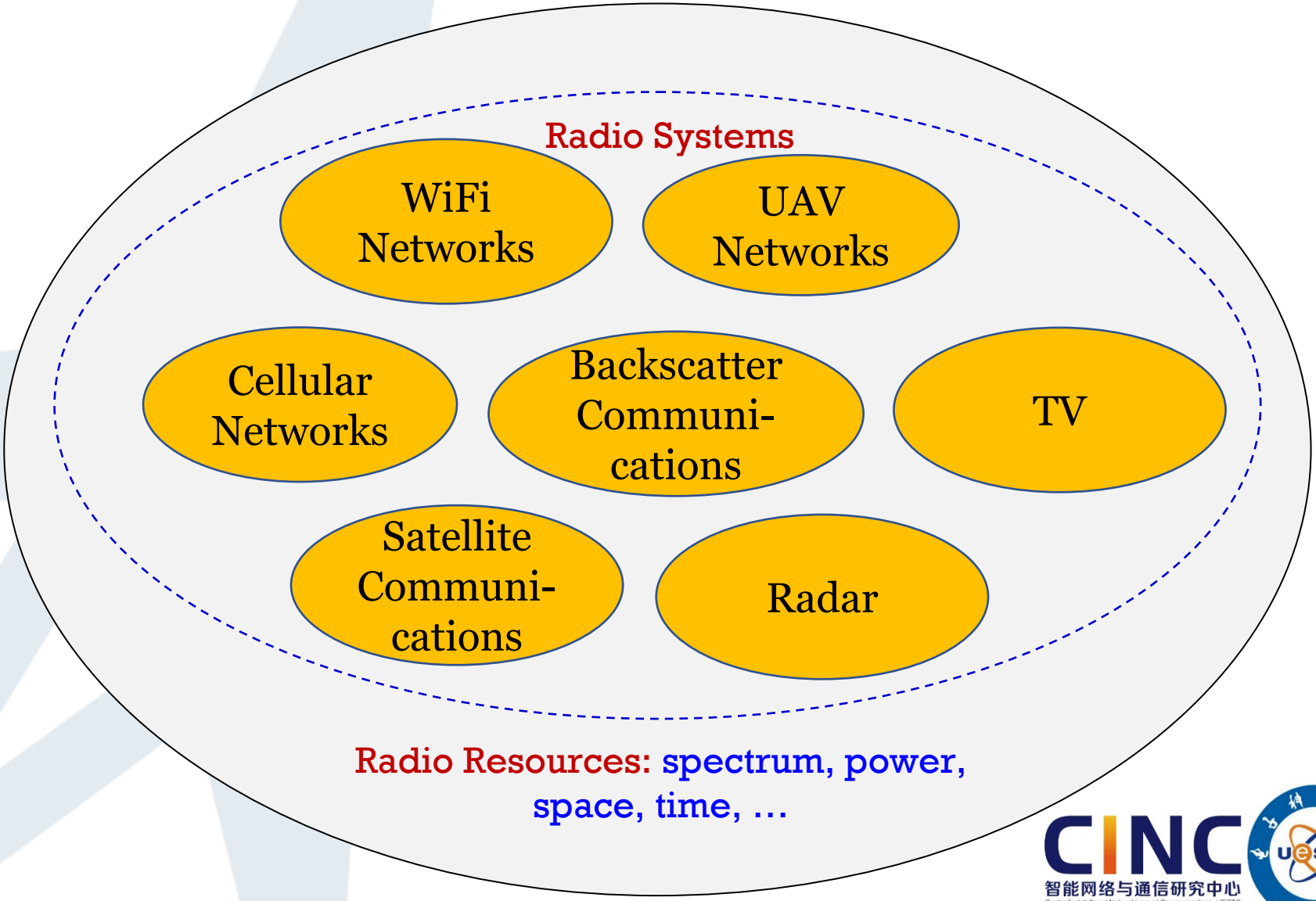
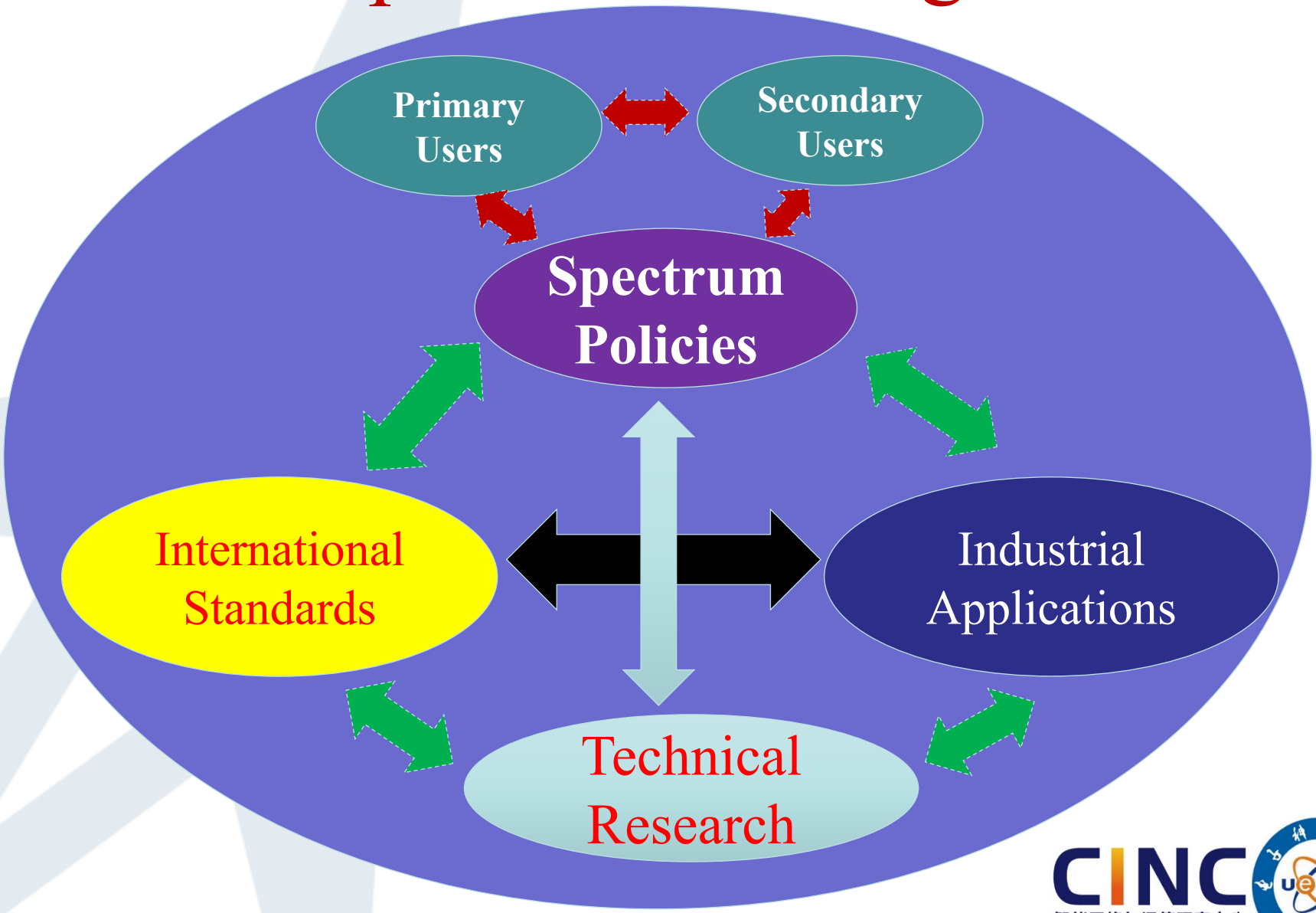
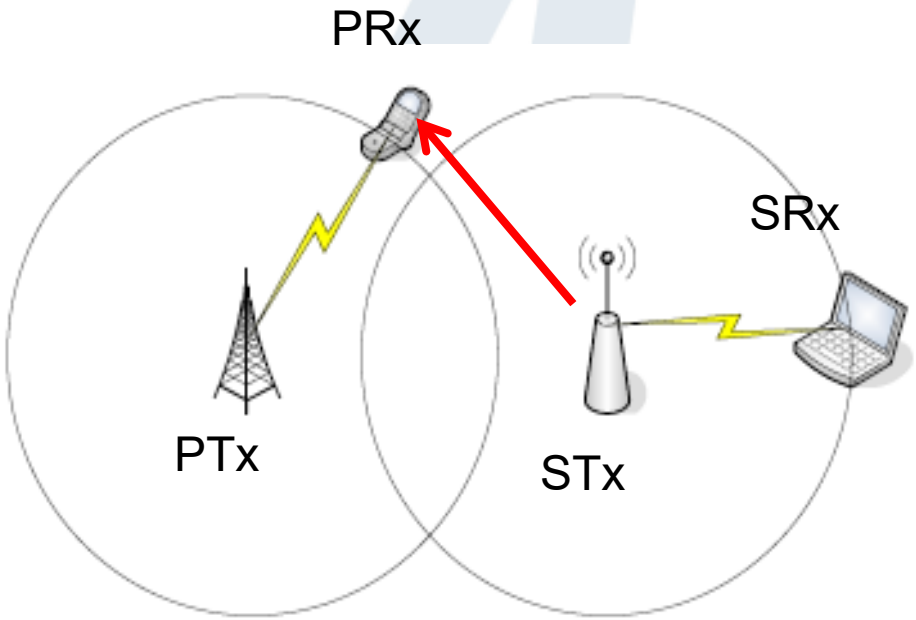
Radio Ecosystem

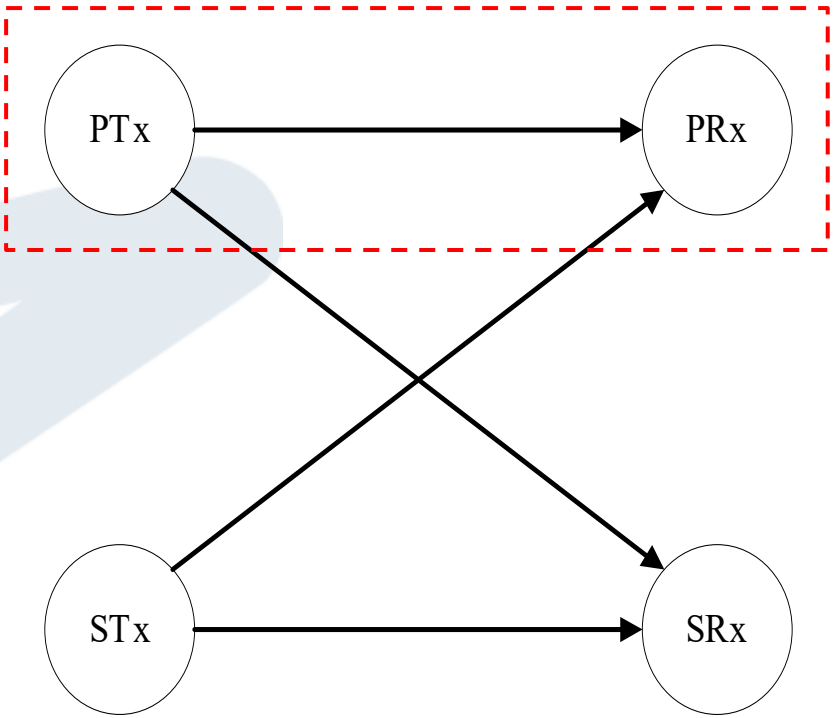


Spectrum Sharing



Cognitive Radio: Competitive Spectrum Sharing





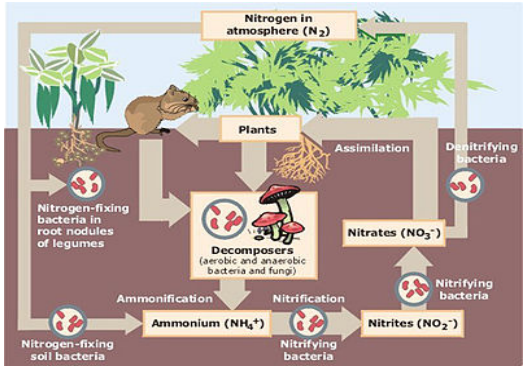
$$C = W \log\left(1 + \frac{P_r}{I + N}\right)$$

Natural Ecosystem

- Natural ecosystems consist of heterogeneous species sharing and/or competing for limited resources.
- In natural ecosystems, members co-evolve and develop, therefore strengthening the whole ecosystem.

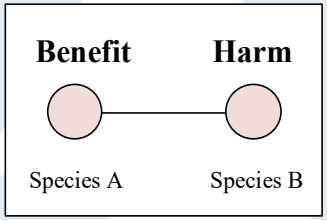
From Competition to Symbiosis

- Biological symbiosis
  - Symbiosis is any type of close and long-term biological interaction between two different biological organisms (also called symbiotic partner).

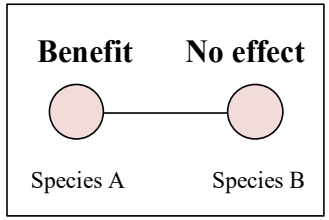


- The interaction occurs via the resource and service exchange.
  - Resources: water, energy…
  - Services: cleaning, pollination…

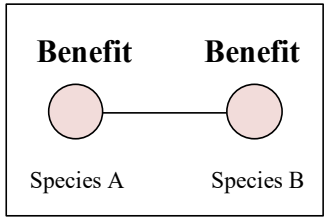
- Symbiotic relationship



Parasitism

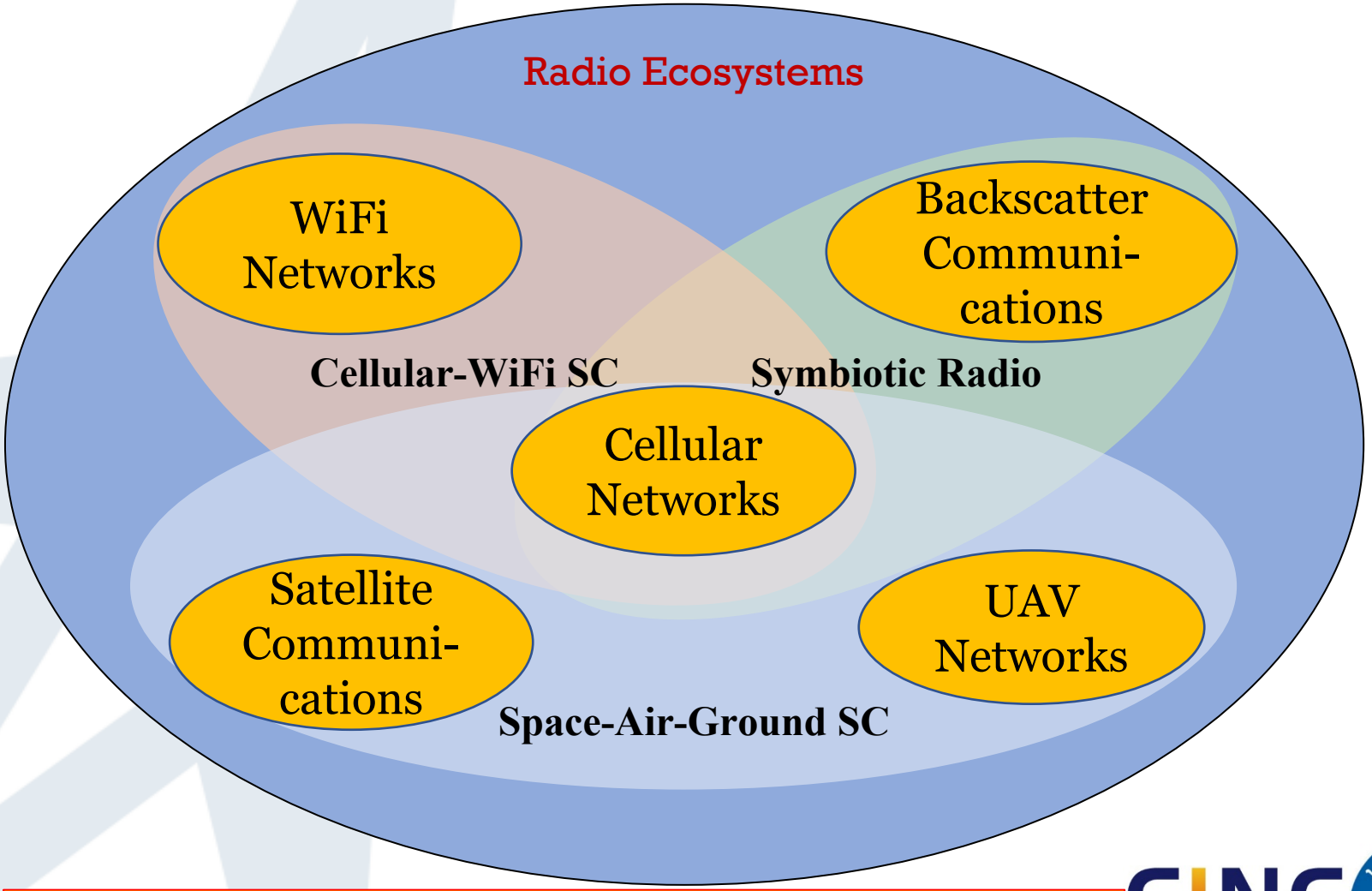


Commensalism



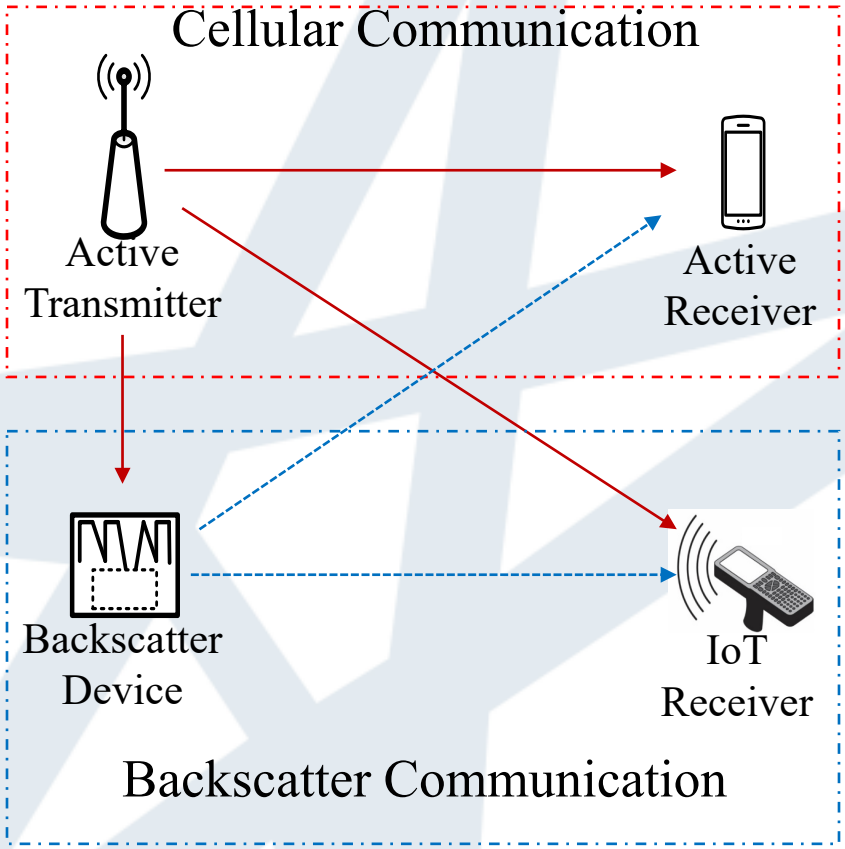
Mutualism

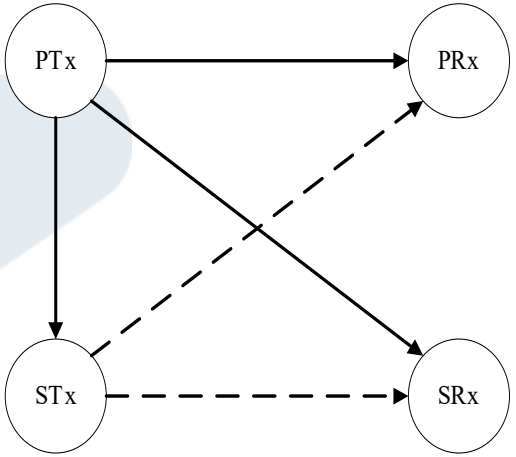
Symbiotic Communications



Y.-C. Liang, R. Long, Q. Zhang and D. Niyato, Symbiotic Communications: Where Marconi Meets Darwin, IEEE Wireless Communications, February 2022.

Symbiotic Radio (SR)

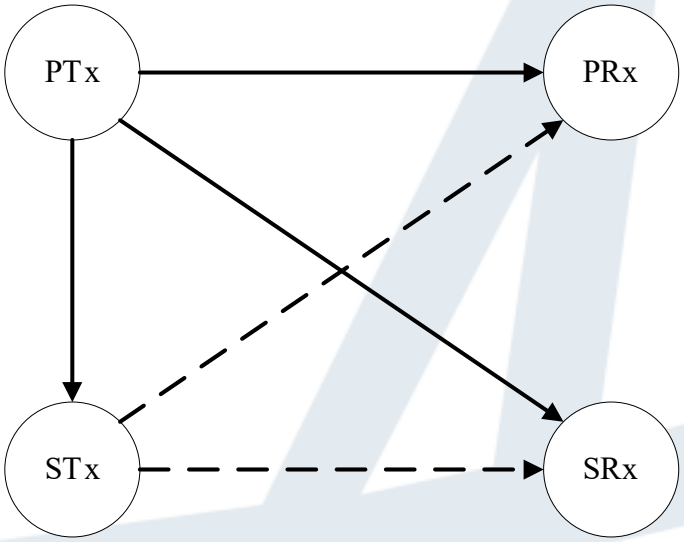


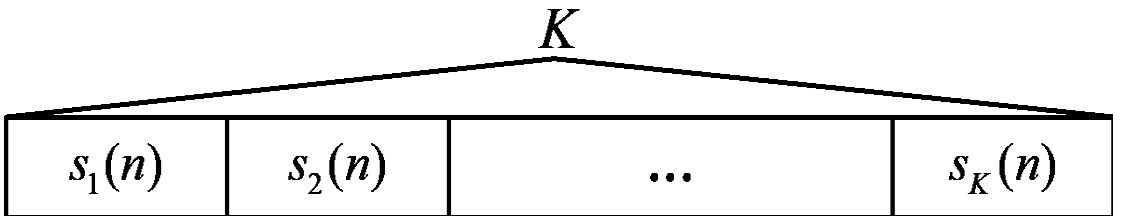


- PTx: Active radio
- STx: Passive radio

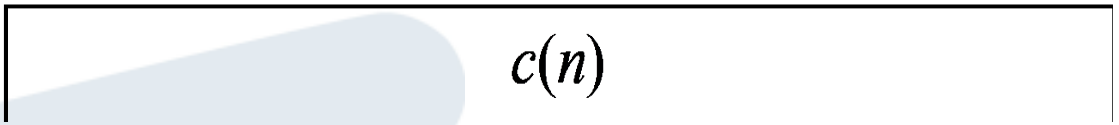
Y.-C. Liang, Q. Zhang, E. Larsson and G. Y. Li, Symbiotic Radio: Cognitive Backscattering Communications for Future Wireless Networks, IEEE Trans Cognitive Comms & Networking, Dec 2020.

System Model for SR





(a) Primary transmission



(b) Secondary transmission

- Assume symbol-rate relation: $T_c = KT_s$ (K is the spreading factor)
- Primary signal: $s_k(n)$, secondary signal: $c(n)$
- Received signal at the SRx: **Modulation in the air**

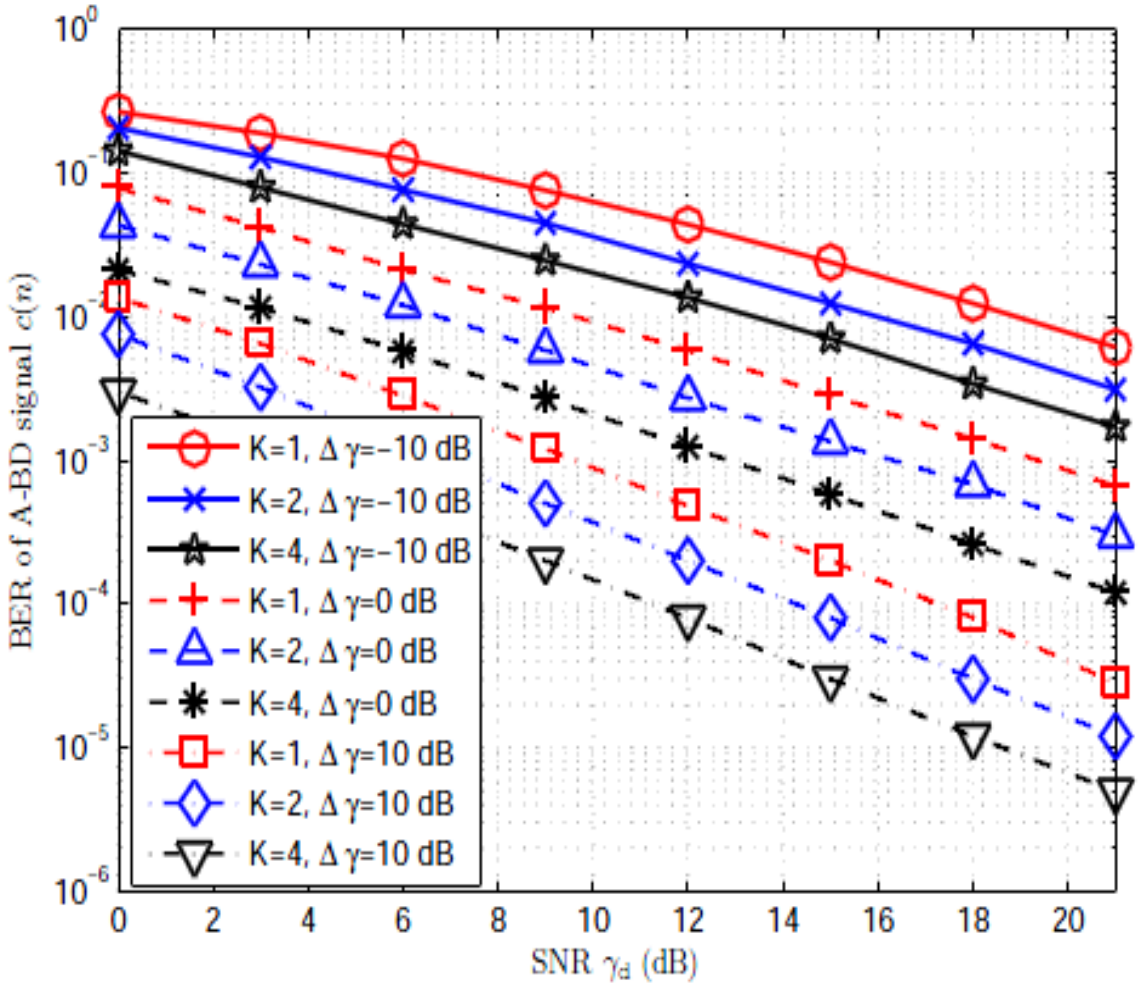
$$\boldsymbol{y}_k(n) = \sqrt{p}\boldsymbol{h}_1 s_k(n) + \sqrt{p}\boldsymbol{h}_2 s_k(n)c(n) + \boldsymbol{u}_k(n)$$

- Received signal at the PRx:

$$\boldsymbol{z}_k(n) = \sqrt{p}\boldsymbol{f}_1 s_k(n) + \sqrt{p}\boldsymbol{f}_2 s_k(n)c(n) + \boldsymbol{v}_k(n)$$

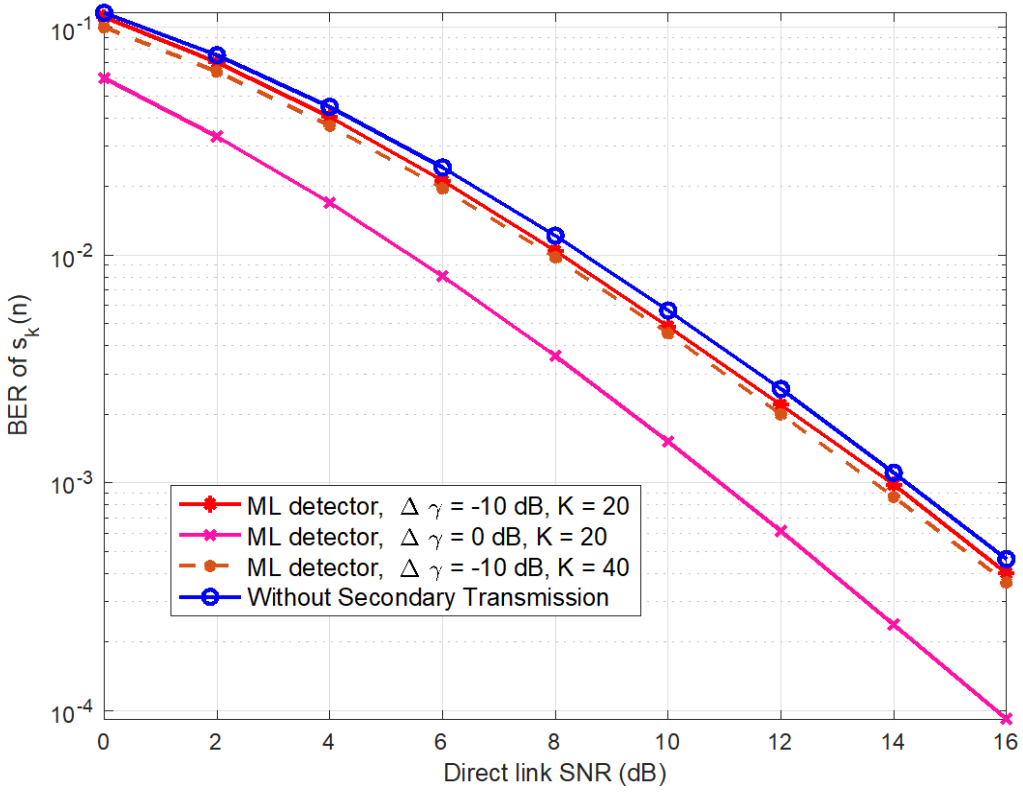
G. Yang, Y.-C. Liang, R. Zhang, and Y. Pei, Modulation in the Air: Backscatter Communications over Ambient OFDM Signals, IEEE Trans Communications, 2018.

Performance of ML Detector



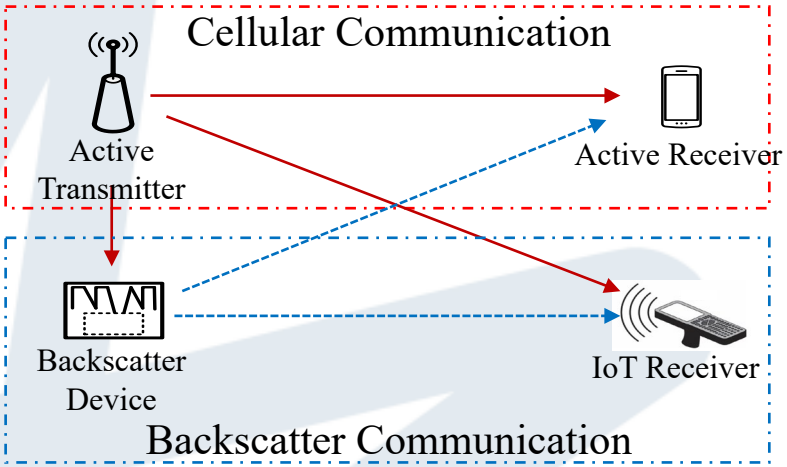
- BER of secondary signal c(n) with different spreading factor
- When spreading factor increases by two times, the data rate of IoT device reduces to half, but an SNR gain of 3 dB is achieved.

Performance of ML Detector



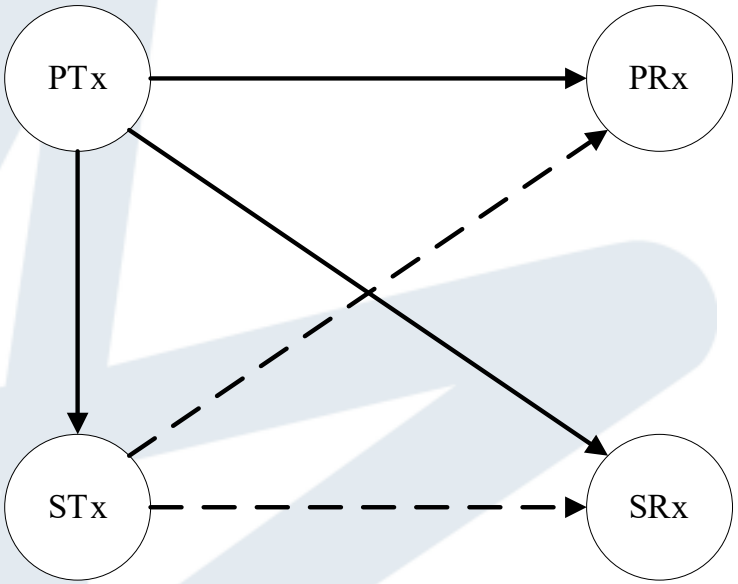
- $M_r = 2$;
- BER performance of $s_k(n)$ achieves around 3 dB SNR gain when $\Delta\gamma = 0$ dB compared to the case without secondary transmission.
- Secondary system has the transmission opportunity;
- Mutualism spectrum sharing

Symbiotic Radio in SC



- Resource-resource Mutualism:
  - Cellular communication: gains additional multipath from the backscatter device (benefits from the backscattered signal energy resources)
  - Backscatter communication: backscatters the cellular signal for transmission (benefits from the cellular spectrum and energy resources)
- Obligate SC: Backscatter cannot realize its communication without the cellular communication.

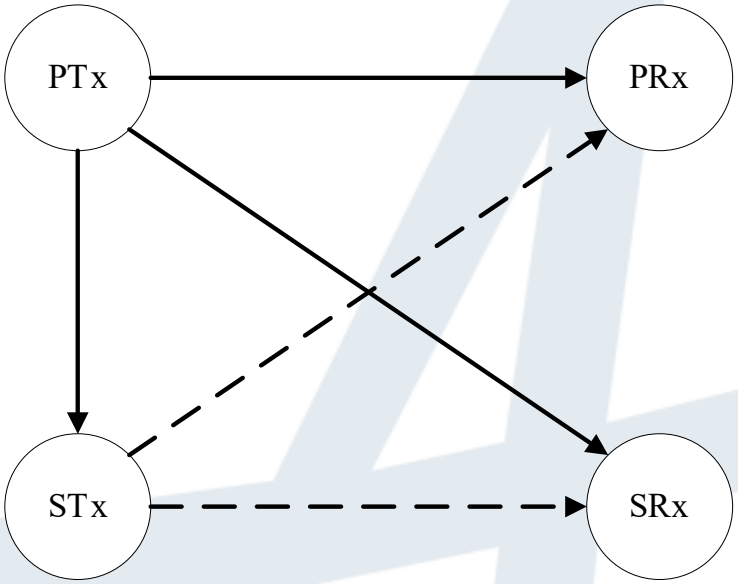
Achievable Rate for Primary System



The PRx can treat the backscattering link as an additional path when decoding the primary symbols:

$$R_s \le \mathsf{E}_c\left[\log_2\left(1+\frac{p\,\|\,\mathbf{f}_1+c\mathbf{f}_2\,\|^2}{\sigma^2}\right)\right]$$

Achievable Rate for Secondary System



$s_k(n)$ is firstly decoded and then the SRx cancels the interference from the direct link signal. When decoding c(n), the primary signal $s_k(n)$ can be viewed as a spreading code with length K.

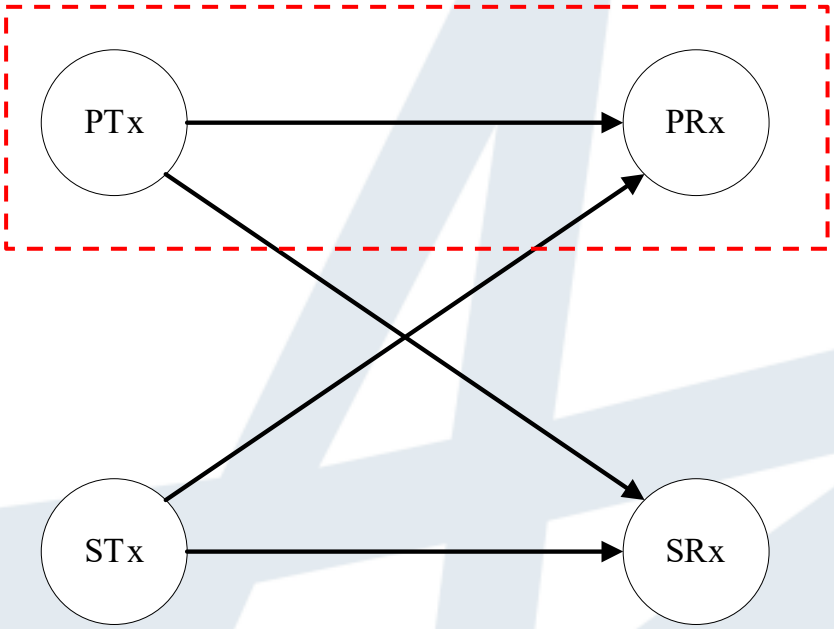
For $K = 1$, the achievable rate of the secondary system is given by:

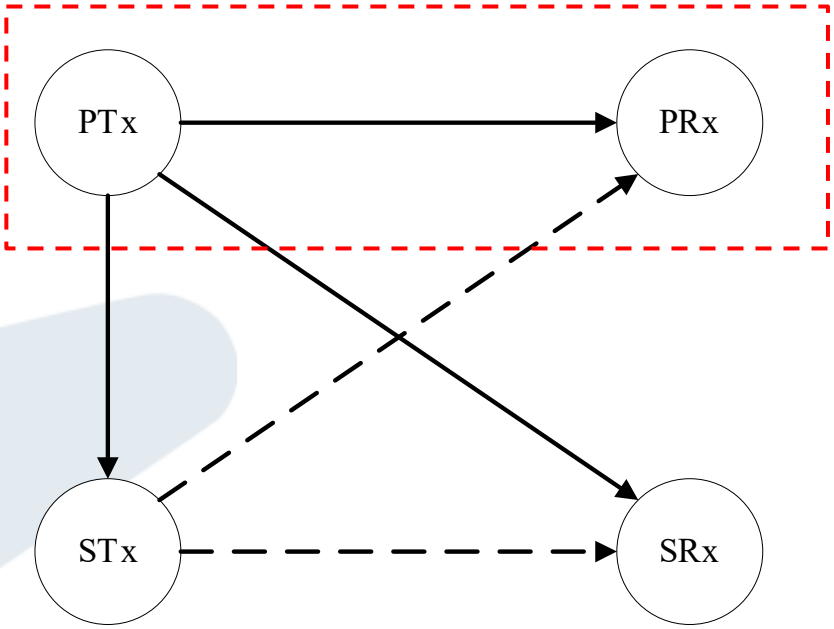
$$R_c = \mathsf{E}_{s_k(n)}\left[\log_2\left(1+\frac{p\,\|\mathbf{h}_2 s_k(n)\|^2}{\sigma^2}\right)\right]$$

For large K, the achievable rate of the secondary system is given by:

$$R_c = \frac{1}{K}\log_2\left(1+\frac{Kp\,\|\mathbf{h}_2\|^2}{\sigma^2}\right)$$

Cognitive Radio (CR) vs SR





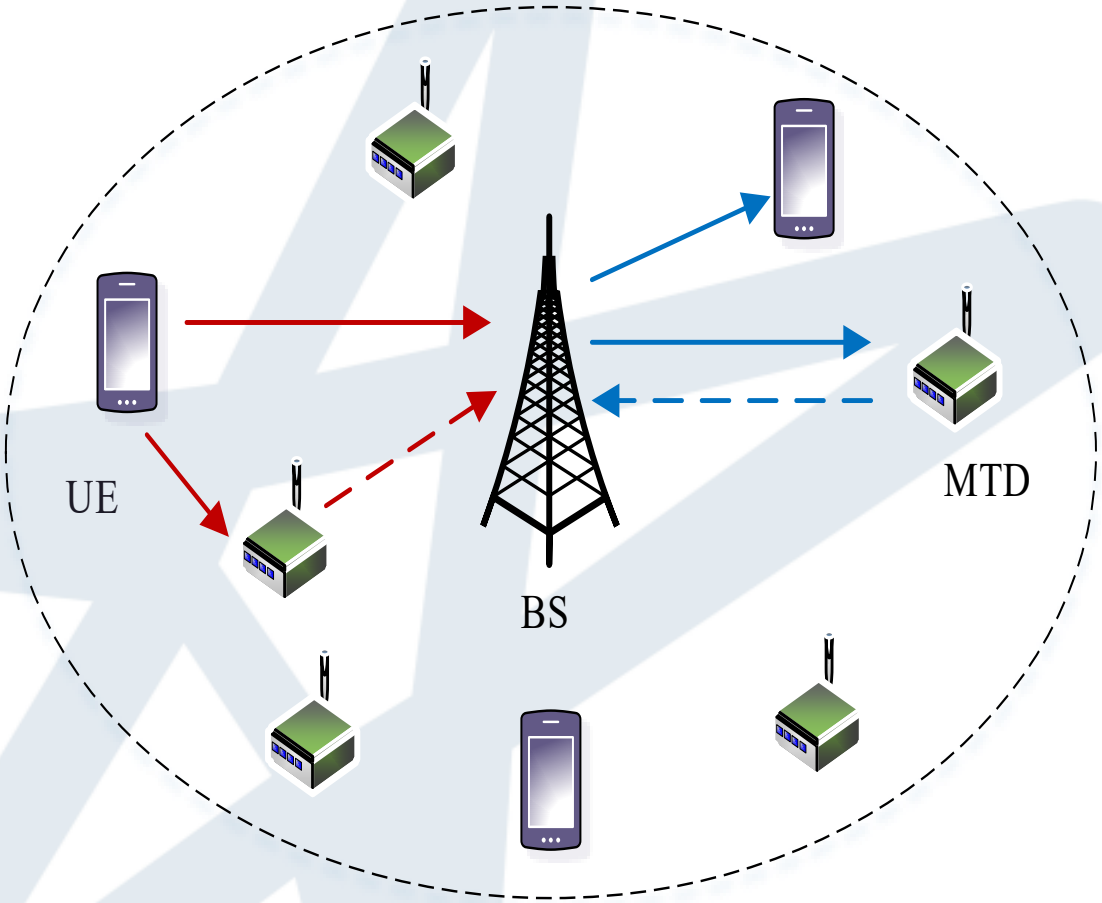
$$C = W \log\left(1 + \frac{P_r}{I + N}\right)$$

$$C = W \log\left(1 + \frac{P_r + f(P_r)}{N}\right)$$

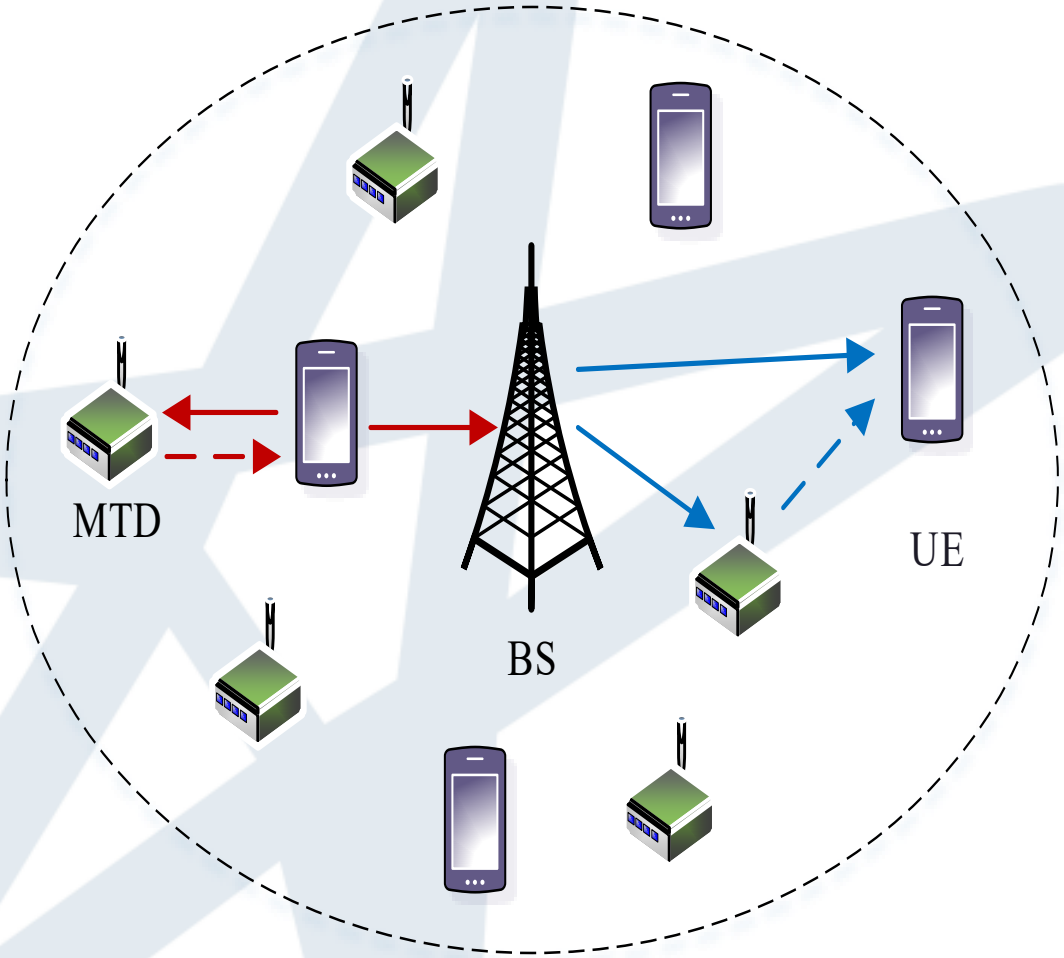
- CR: Interfering relationship
- SR: Mutualism relationship

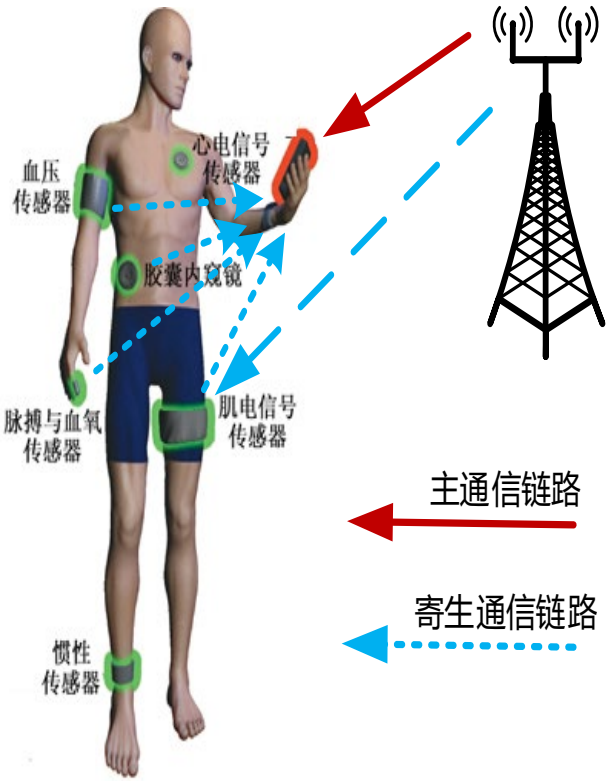
Y.-C. Liang, Q. Zhang, E. Larsson and G. Y. Li, Symbiotic Radio: Cognitive Backscattering Communications for Future Wireless Networks, IEEE Trans Cognitive Comms & Networking, Dec 2020.

BS-Centric SR



UE-Centric SR





Summary

- Symbiotic communication is a new paradigm for communication system design
  - Breaking the boundary of radio systems
  - A fresh perspective on radio resource management
- Symbiotic radio is promising scheme to support massive access for 6G and beyond
  - No need to have a dedicated radio spectrum
  - No need to have dedicated RF sources
  - Low power consumption due to the use of backscattering radio technology
  - Zero-energy devices when energy harvesting is incorporated

More Readings on SR

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SR for 6G

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- S. Chen, Y.-C. Liang, S. Sun, S. Kang, W. Cheng, and M. Peng, Vision, requirements, and technology trend of 6G: how to tackle the challenges of system coverage, capacity, user data-rate and movement speed, IEEE Wireless Commun., vol. 27, no. 2, pp. 218–228, 2020.
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Thanks for Your Attention!