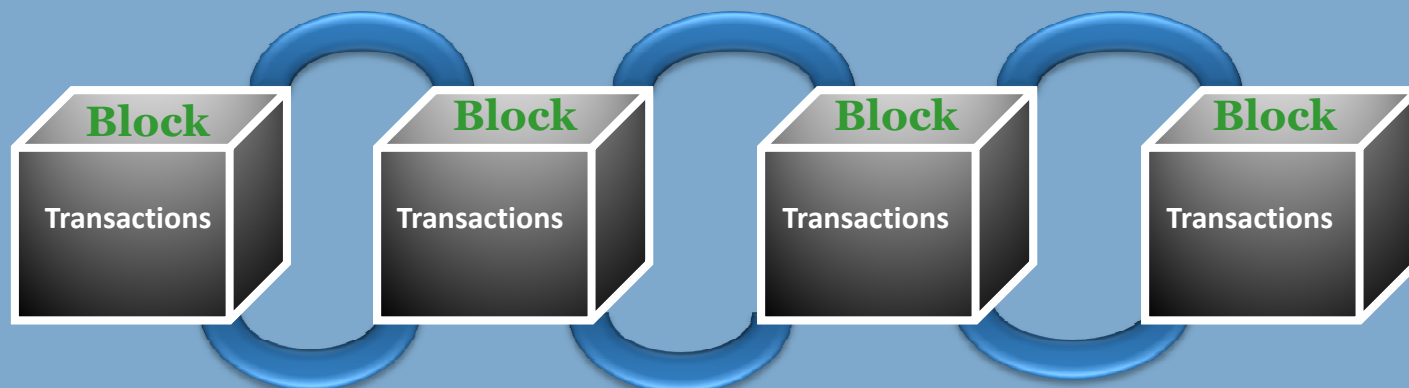


Cognitive Radio Networks and Blockchain

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- Wireless Radio Spectrum
- Cognitive Radio Networks
 - White spaces
- Blockchain
- Cognitive Radio Networks and Blockchain Applications
 - Spectrum Tracking
 - Spectrum Trading

Operating Features of Wireless Standards



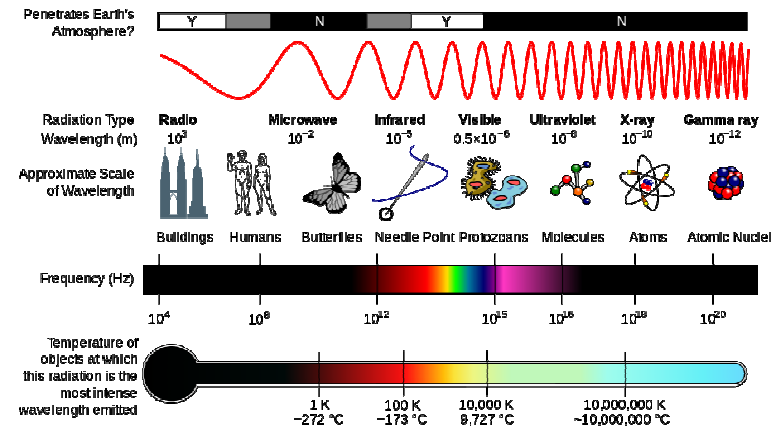
Wireless Standard	Frequency Band	Deployment	Application
AM	531-1611 kHz	Outdoors	Radio broadcast
FM	66-108 MHz	Outdoors and Indoors	High quality audio over radio broadcast
GSM, CDMA, LTE	700-2600 MHz	Outdoors and Indoors	Cellular Voice and Data
IEEE 802.15.1 (Bluetooth)	2.4 – 2.485 GHz	Most Indoors	Short range communication
IEEE 802.11 (Wi-Fi)	2.4 GHz, 5 GHz, 60 GHz	Indoor and Campus wide	WLAN
IEEE 802.20	3.5 GHz	Outdoors	Mobile broadband

Wireless Radio Spectrum is a natural resource!

Wireless Radio Spectrum



- Licensed band
- Unlicensed band
 - Industrial, Scientific, and Medical (ISM)
 - Defined in ITU Radio Regulations
 - Applications
 - Cordless Phones
 - Bluetooth devices
 - Near Field Communication (NFC) devices
 - Wi-Fi
 - Garage door openers
- Germany raised 6.55 Billion € for 5G mobile spectrum auction
 - For 420 MHz of spectrum block is auctioned by Federal Network Regulator (BNetzA)
- Fixed Spectrum Assignment Policy



Source: https://en.wikipedia.org/wiki/Electromagnetic_spectrum

Wireless Radio Spectrum Map – USA (FCC)

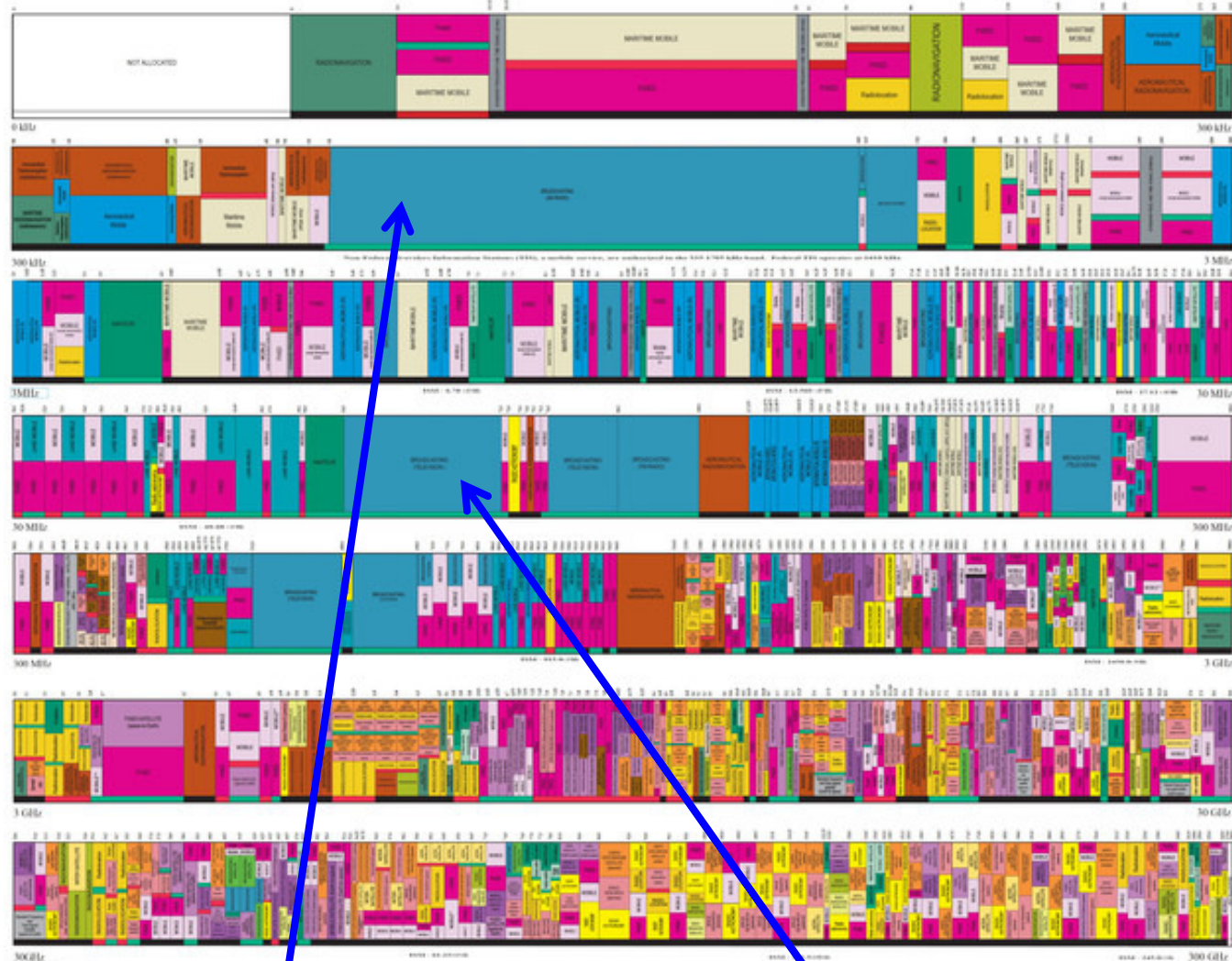


UNITED STATES FREQUENCY ALLOCATIONS

THE RADIO SPECTRUM

RADIO SERVICES COLOR LEGEND		
	Aeronautical mobile (AM)	Aeronautical mobile (A)
	Aeronautical mobile (AM) - Land mobile	Aeronautical mobile (A) - Land mobile
	Aeronautical mobile (AM) - Maritime	Aeronautical mobile (A) - Maritime
	AM	AM
	AM - Land mobile	AM - Land mobile
	AM - Maritime	AM - Maritime
	AM - Land mobile	AM - Land mobile
	AM - Maritime	AM - Maritime
	AM - Land mobile	AM - Land mobile
	AM - Maritime	AM - Maritime
	AM - Land mobile	AM - Land mobile
	AM - Maritime	AM - Maritime
	AM - Land mobile	AM - Land mobile
	AM - Maritime	AM - Maritime
	AM - Land mobile	AM - Land mobile
	AM - Maritime	AM - Maritime
	AM - Land mobile	AM - Land mobile
	AM - Maritime	AM - Maritime
	AM - Land mobile	AM - Land mobile
	AM - Maritime	AM - Maritime
ACTIVITY CODE		
	Mobile	
	Fixed	
	Mobile	
ALLOCATION USAGE DESIGNATION		
	Primary	
	Secondary	
	Shared	
	Co-primary	
	Co-secondary	
	Co-shared	

U.S. DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Office of Spectrum Management
1004 JUNE 2016



Broadcasting: AM Radio

Broadcasting: Television

Wireless Radio Spectrum Map – UK (Ofcom)

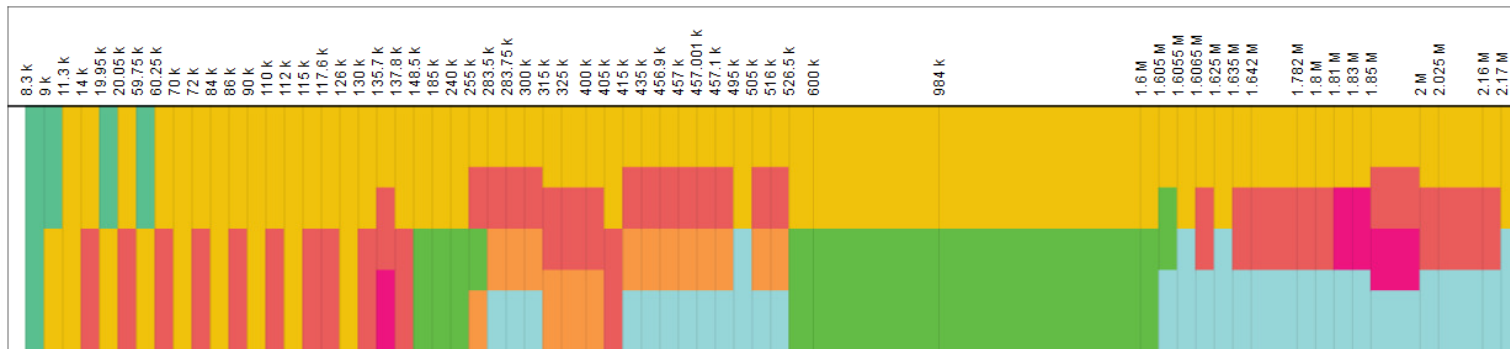


Filter by sector

- Space Science
- Licence exempt
- Public sector
- Amateur
- Broadcasting
- Aeronautical
- Maritime
- Business Radio
- PMSE
- Satellite
- Mobile and Wireless broadband
- Fixed Links

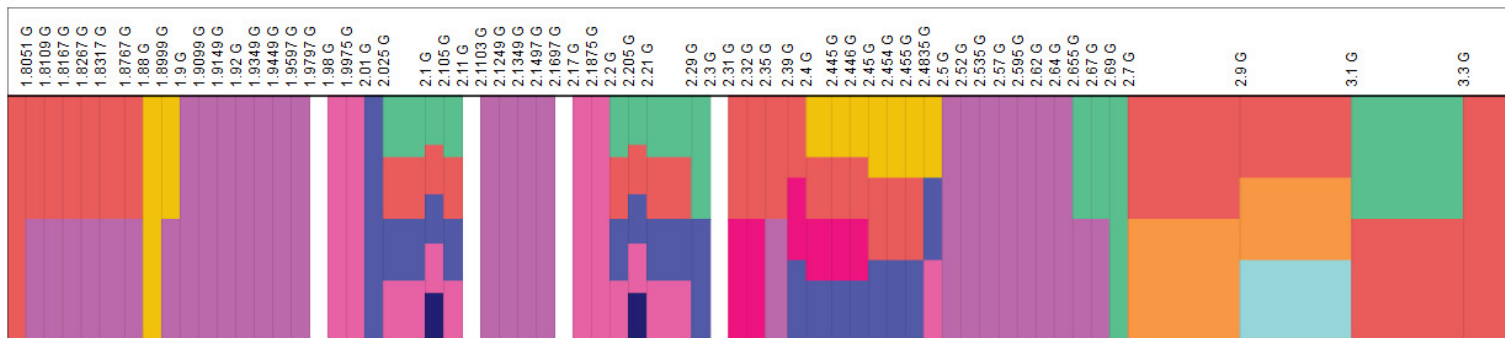
Range of 0 Hz - 2.1905 MHz

Print page: [Map](#) [Map & table](#) [Table](#)



Range of 1.805 - 3.4 GHz

Print page: [Map](#) [Map & table](#) [Table](#)

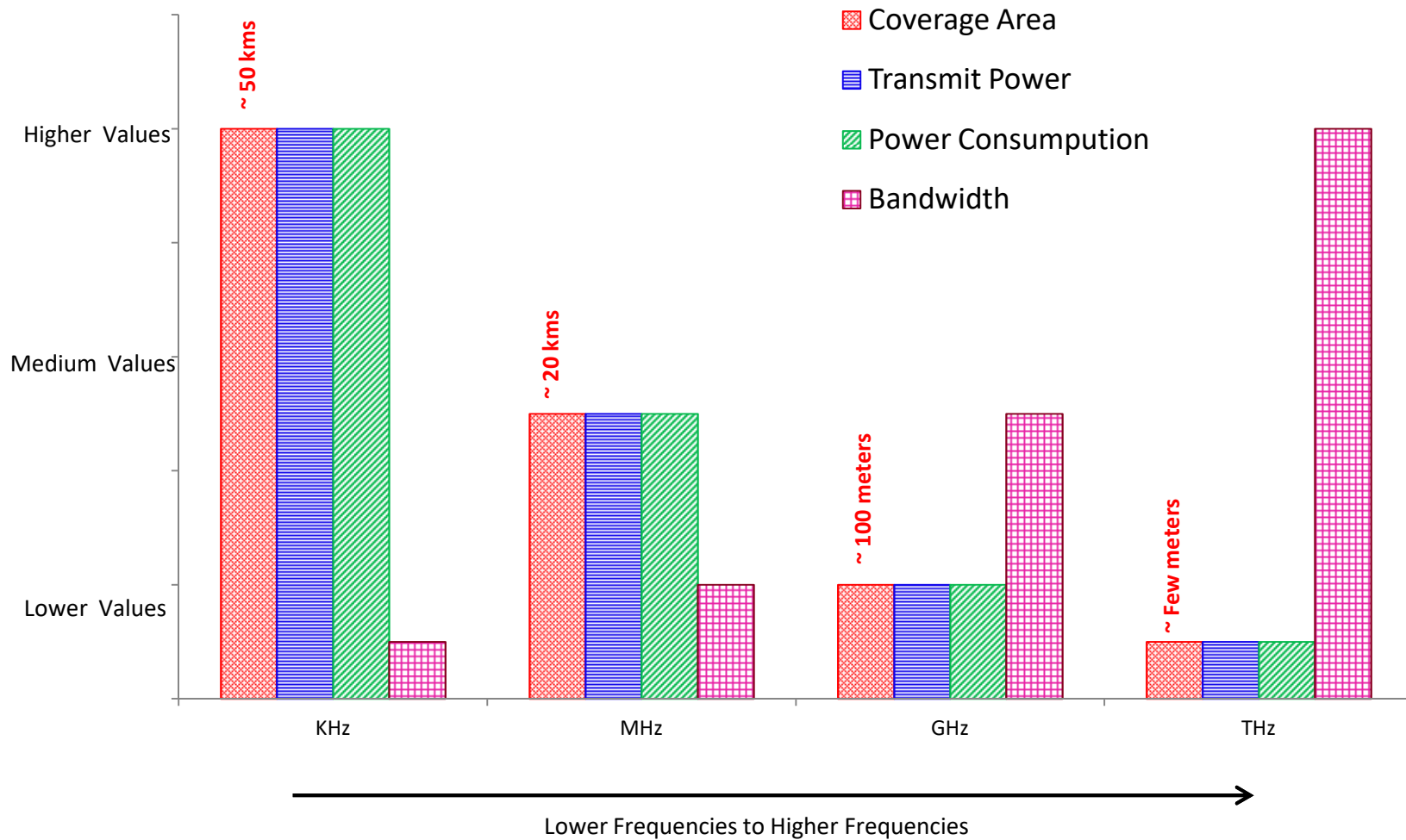


Wireless Radio Spectrum Map – Ireland (ComReg)



Frequency Band (GHz)	ITU	European	National Usage	Legislation	CEPT	Notes
		ECA17A	IRL1			
10.55 - 10.6 GHz	FIXED	FIXED	FWALA (10.15-10.3 and 10.5-10.65 GHz)	National Legislation: S.I. 79 of 2003 S.I. 530 of 2003	ERC/REC 12-05	FWA services (10.5 – 10.65 GHz). See ComReg document 06/17R7 for details of band plan and pairing arrangements.
	MOBILE EXCEPT AERONAUTICAL MOBILE	MOBILE EXCEPT AERONAUTICAL MOBILE				
	Radiolocation	Radiolocation				
			PMSE		ERC/REC 25-10	See ComReg document 08/08R, as revised.
			ECA17A	IRL1		
10.6 - 10.68 GHz	EARTH EXPLORATION-SATELLITE (passive)	EARTH EXPLORATION-SATELLITE (passive)				
	FIXED	FIXED	FWALA (10.15-10.3 and 10.5-10.65 GHz)	National Legislation: S.I. 79 of 2003 S.I. 530 of 2003	ECC/DEC/(10)01	FWA services (10.5 – 10.65 GHz). See ComReg document 06/17R7 for details of band plan and pairing arrangements

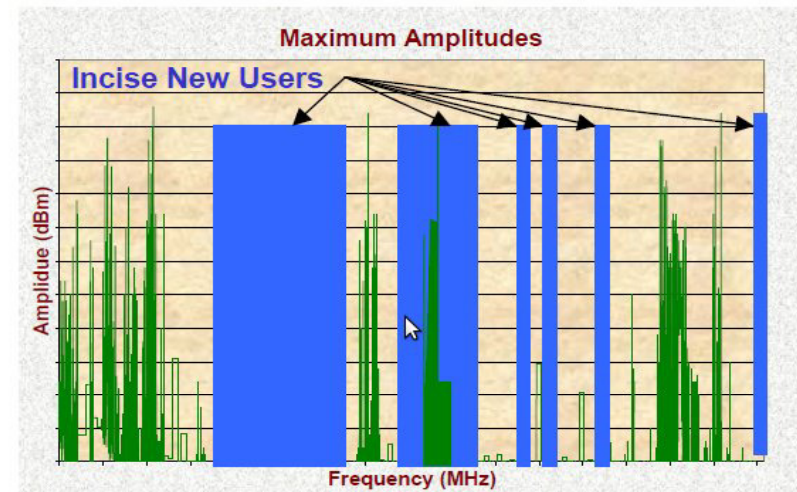
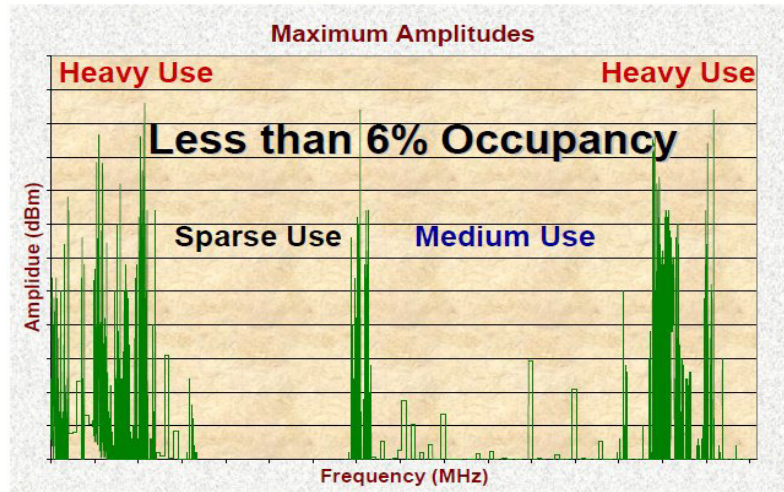
Behavior of Wireless Radio Spectrum



Wireless Radio Spectrum Occupancy



...Most Spectrum Is Unused!



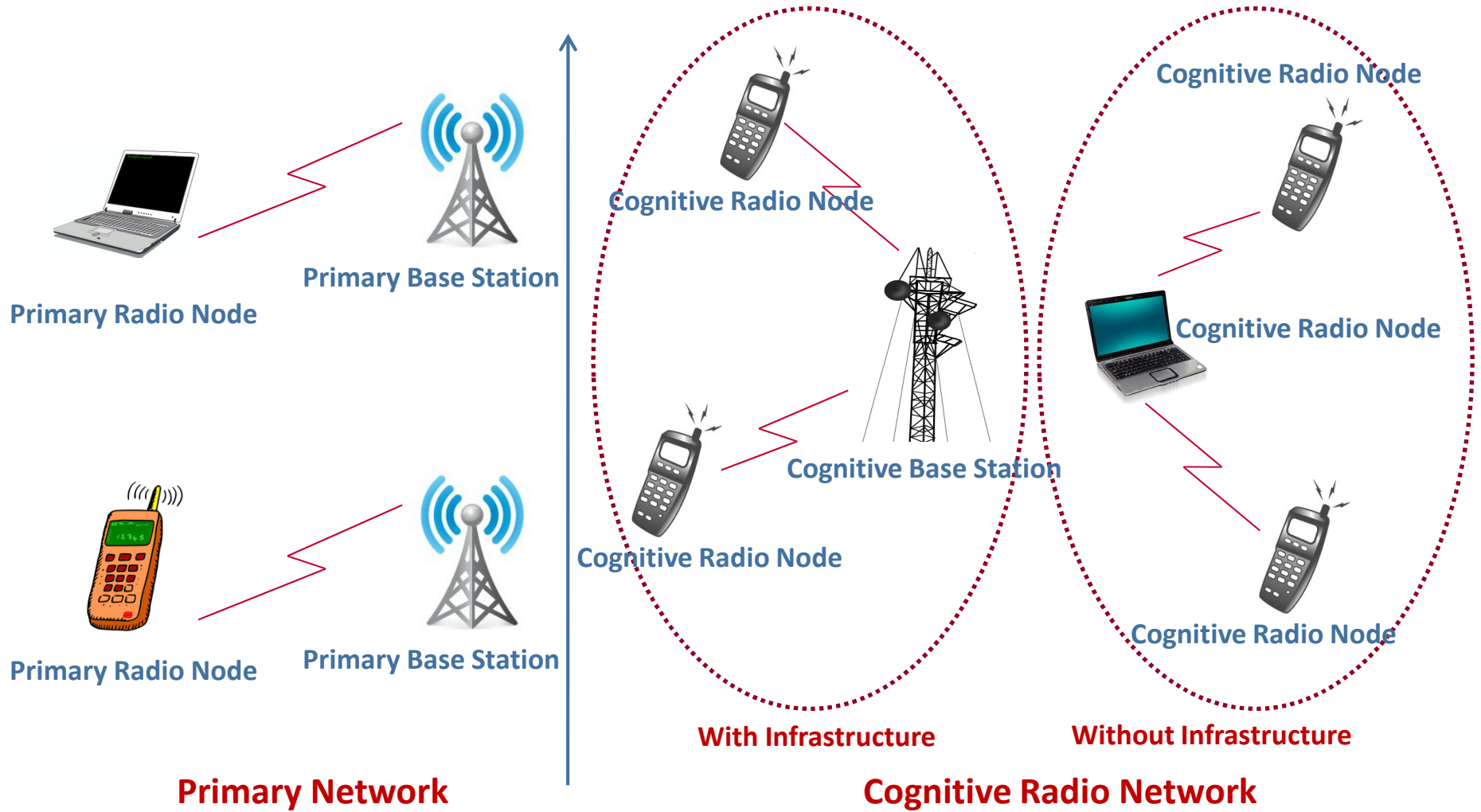
- Due to:
 - Fixed spectrum assignment policy
 - Limited available spectrum in today's wireless network
- Results In:
 - Inefficiency in spectrum usage
 - Creation of Spectrum Holes → White space

[1] I. F. Akyildiz, W.-Y. Lee, M. C. Vuran, and S. Mohanty, "Next generation/dynamic spectrum access/cognitive radio wireless networks: a survey," Computer Networks, vol. 50, Issue 13, pp. 2127 – 2159, 2006.

- Cognitive Radio (CR)
 - A “radio” that can be programmed and configured dynamically
 - Can change its transmission or reception parameters
 - A.k.a., Secondary User
- Cognitive Radio Networks
 - Primary User (PU) → Licensed User
 - Secondary User (SU) → Unlicensed User
- CR opportunistically use the wireless radio spectrum
 - CR transmissions should not degrade the reception quality of Primary Radio (PR) nodes
 - CR node should immediately interrupt its transmission whenever any neighboring PR activity is detected

- Cognitive Radio nodes opportunistically exploit the licensed band
- **Spectrum Sensing**: Detect unused spectrum and presence of licensed users
- **Spectrum Management**: Select best available channel
- **Spectrum Sharing**: Coordinate access to this channel with other users
- **Spectrum Mobility**: Vacate the channel when a licensed user is detected and maintaining seamless communication

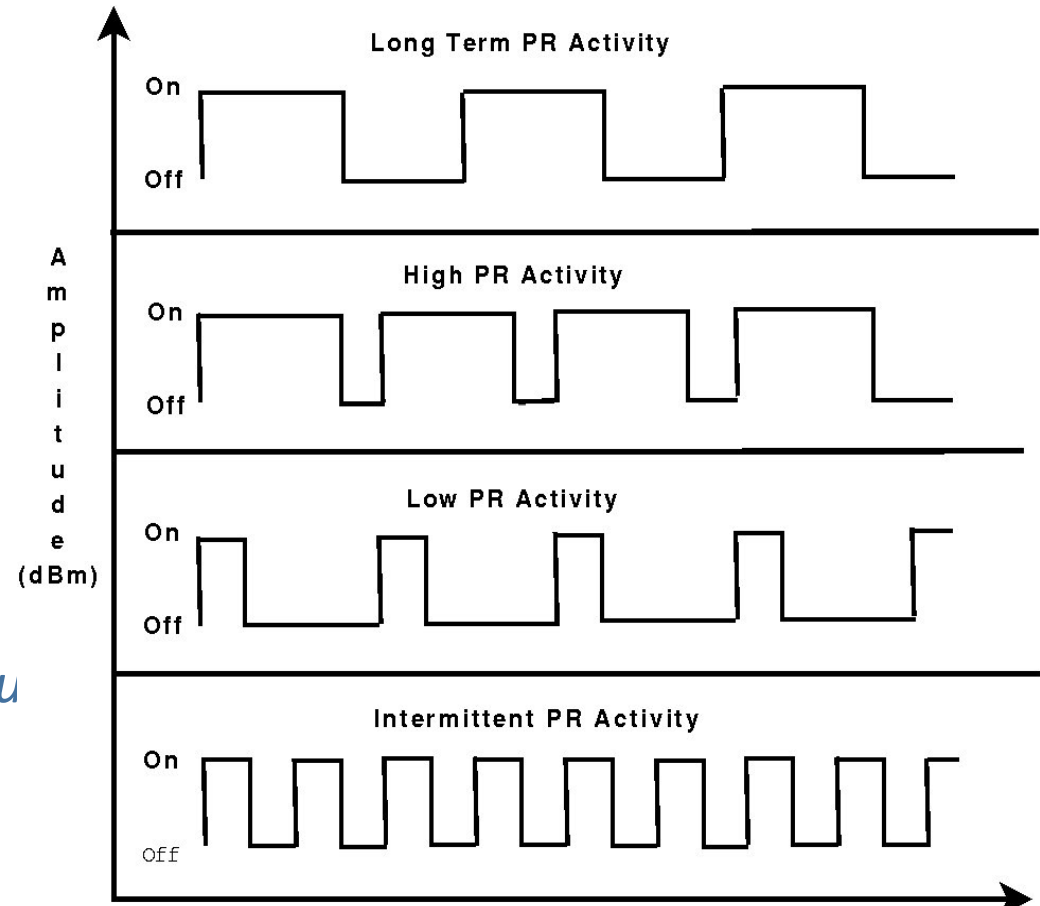
Cognitive Radio Network Architecture



PR Nodes Activity Pattern



- *Long Term PR Activity:*
 - *Long ON and Long OFF*
 - *Free call packages*
- *High PR Activity:*
 - *Long ON and Short OFF*
 - *Rush hours, urban areas*
- *Low PR Activity:*
 - *Short ON and Long OFF*
 - *Remote areas, less peak hou*
- *Intermittent PR Activity:*
 - *Short ON and Short OFF*
 - *Bus stations, railway stations*



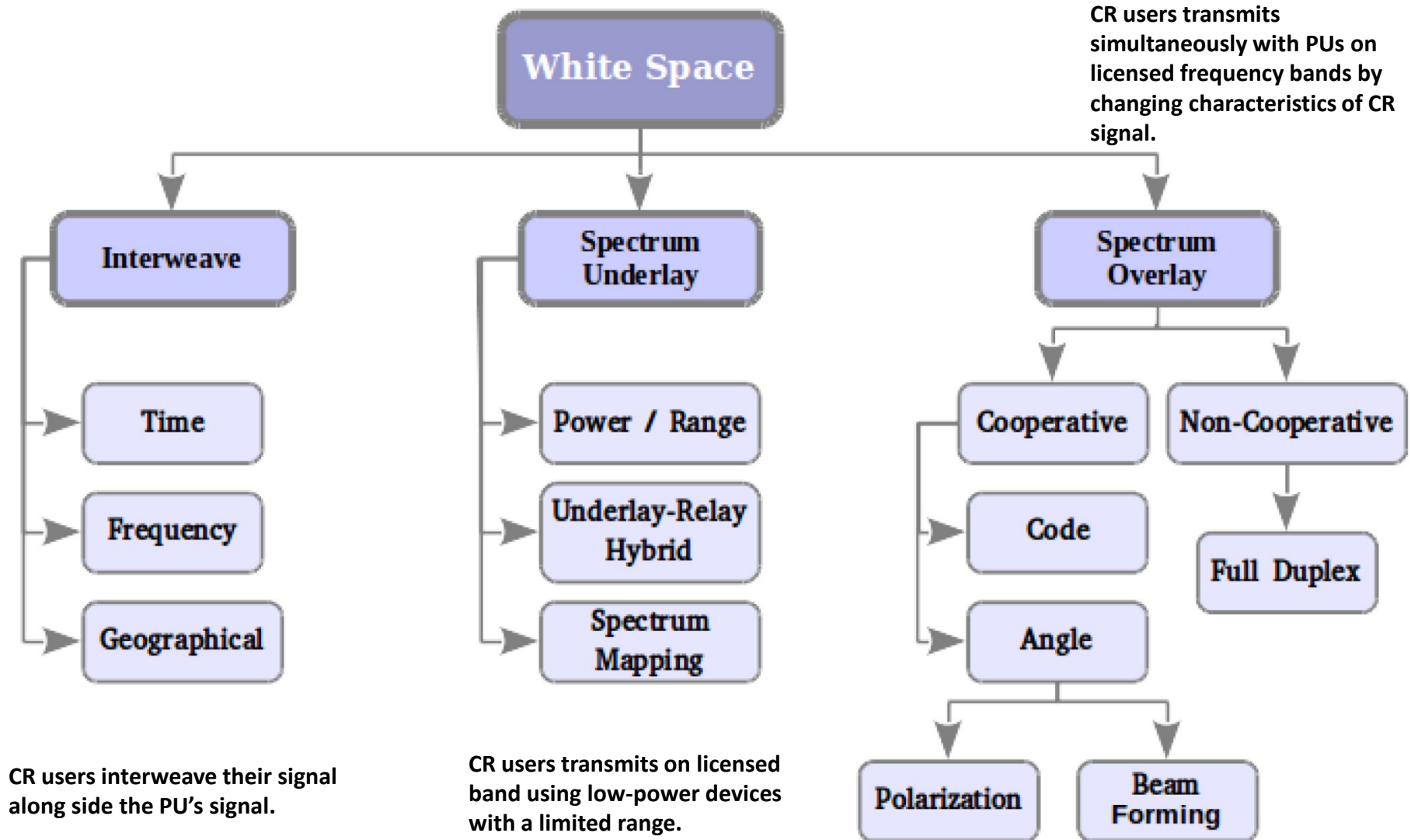
CR node's goal is to identify these activities!
White Space

- A white space is an unused radio frequency band
- Its existence depends upon time, frequency and geographical band
- Its utilization does not cause harmful interference to primary users

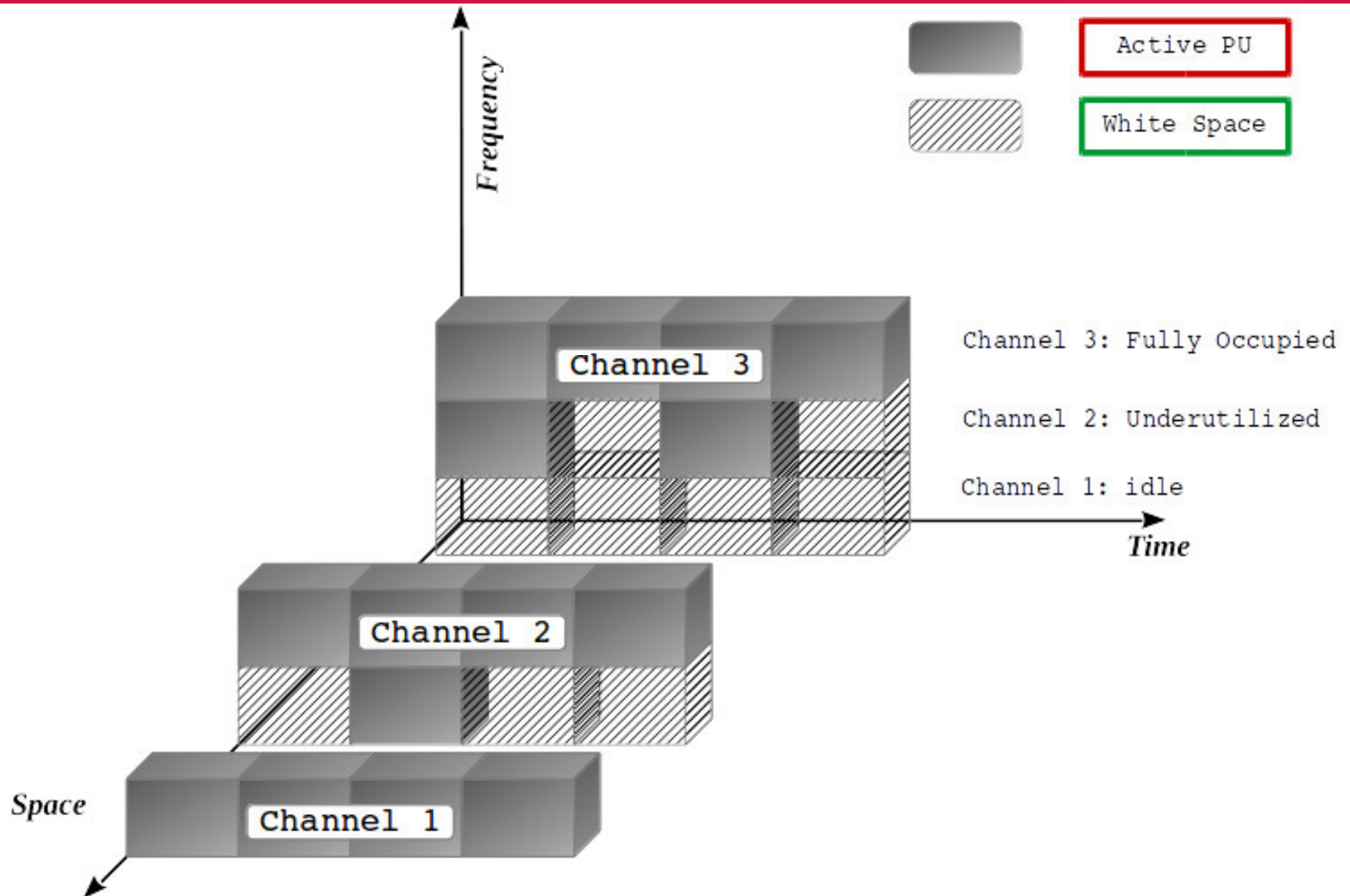
Next, it is shown that white space

- Do not necessarily exist only in an idle band,
- Are not necessarily limited to specific dimensions of the signal space, and
- Are not necessarily limited to licensed frequency bands

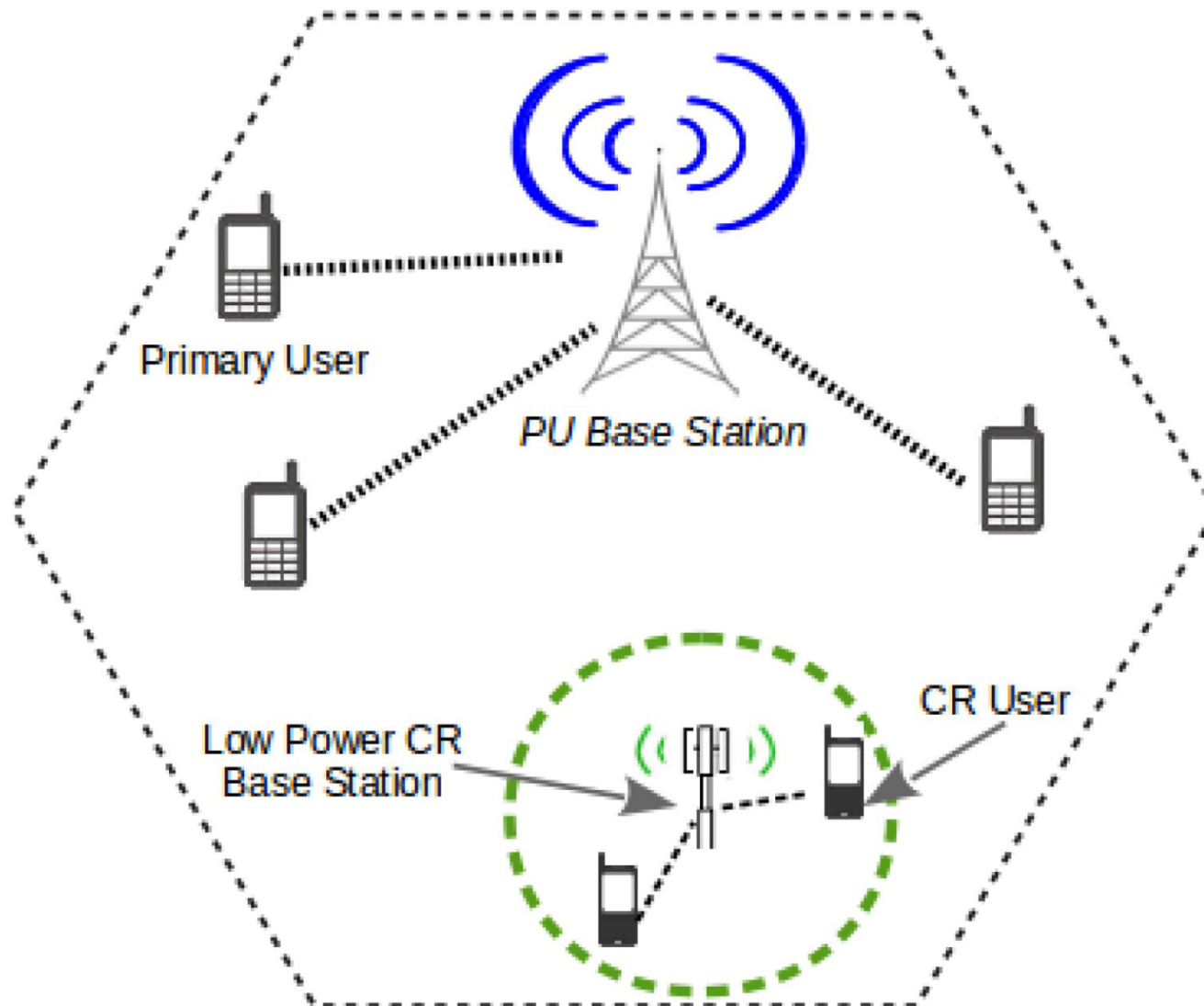
White Space



White Space in Interweave Paradigm



Underlay Communication

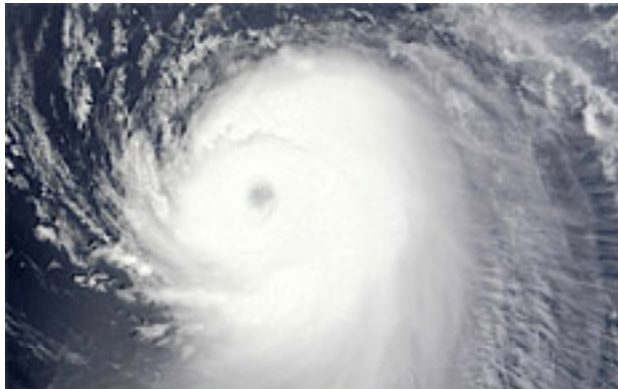


Use of Cognitive Radio Networks



- Tactical Networks – Behind the Enemy Lines
- TV White Space – *IEEE 802.22*
- White-Fi – *IEEE 802.11af* – *WLAN operation in TVWS*
- Cognitive Radio based Smart Grid (CRSG)
- Cognitive Radio Sensor Networks (CRSN)
- Cognitive Radio based Disaster Response Networks
- Cognitive Radio based Wi-Fi
- Cognitive Radio based Satellite Communication
- Cognitive Radio Cellular Networks

Telecommunication Infrastructure Destruction through Natural Disasters



Restoration of Partially Destroyed Telecommunication Networks and CRNs



- Instantaneous deployment of core telecommunication infrastructure is not feasible
 - Due to planning and cost
 - E.g. base stations in the case of cellular networks
- Quick need to help rescue team members and NGOs
 - To facilitate organized help
 - Rehabilitation works

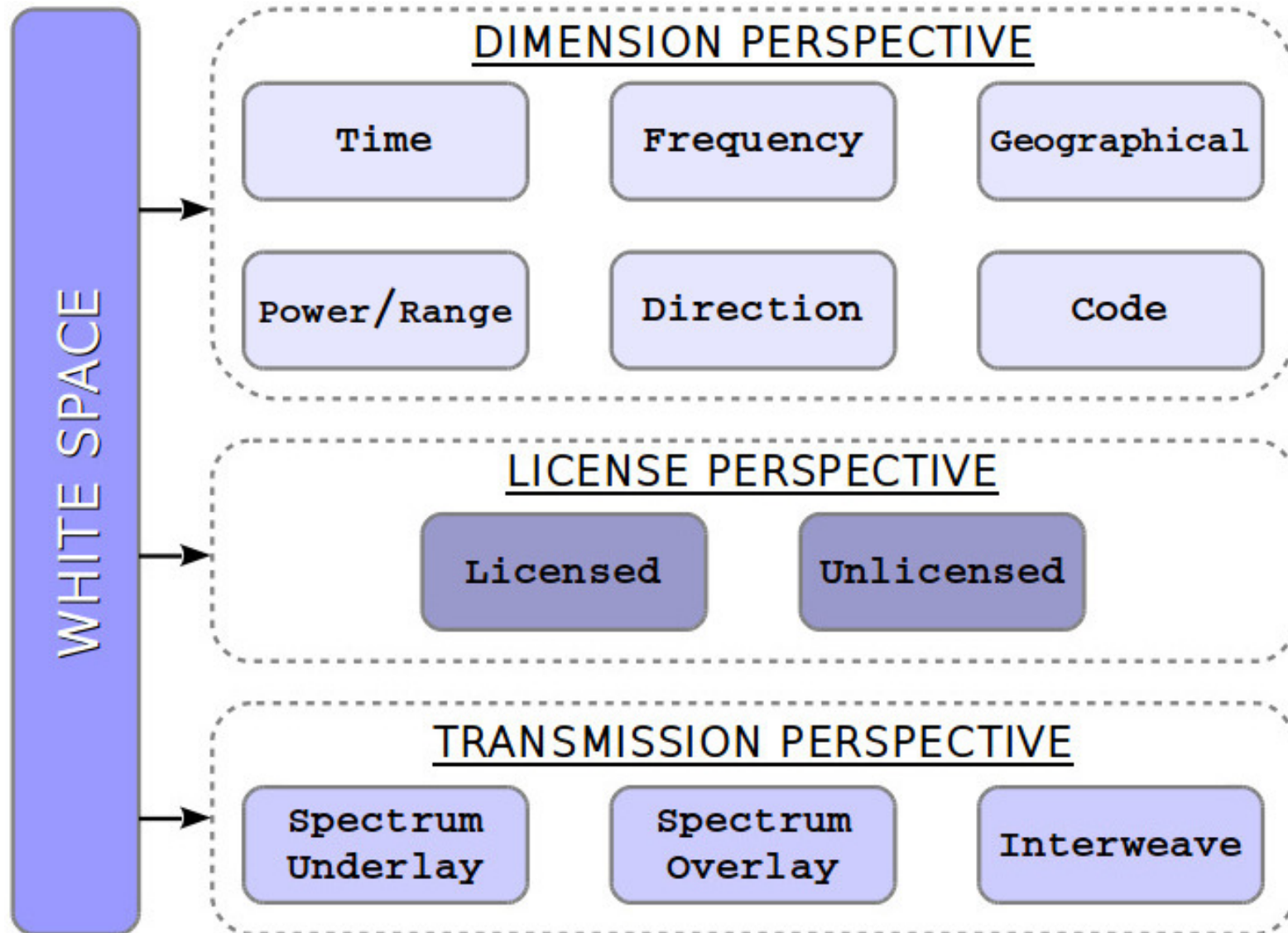
Need for Disaster Response Networks

To provide connectivity and Internet access

Cognitive Radio Networks

Source: S. Ghafoor, P. D. Sutton, C. J. Sreenan and K. N. Brown, "Cognitive radio for disaster response networks: survey, potential, and challenges," in *IEEE Wireless Communications*, vol. 21, no. 5, pp. 70-80, October 2014.

Summary: Future Cognitive Radio Communication



Blockchain Technology

Setting the Context and Background

Crypto Currency Price (Sep 2019)



#	Crypto Currencies	Market Cap	Price
1	Bitcoin 	\$180,753,854,317	\$10,081.66
2	Ethereum 	\$19,321,339,299	\$179.41
3	XRP 	\$11,065,349,258	\$0.257188
4	Bitcoin Cash 	\$5,430,496,998	\$301.75
5	Litecoin 	\$4,480,564,995	\$70.86
6	EOS 	\$3,487,353,962	\$3.74
7	Binance Coin 	\$3,353,638,703	\$21.56
8	Bitcoin SV 	\$2,207,462,185	\$123.63
9	Monero 	\$1,220,939,742	\$70.97
10	Cardano 	\$1,189,244,517	\$0.045869

Source: <https://coinmarketcap.com/coins/>

Bitcoin and Ether are based on Blockchain



Bitcoin

Ether



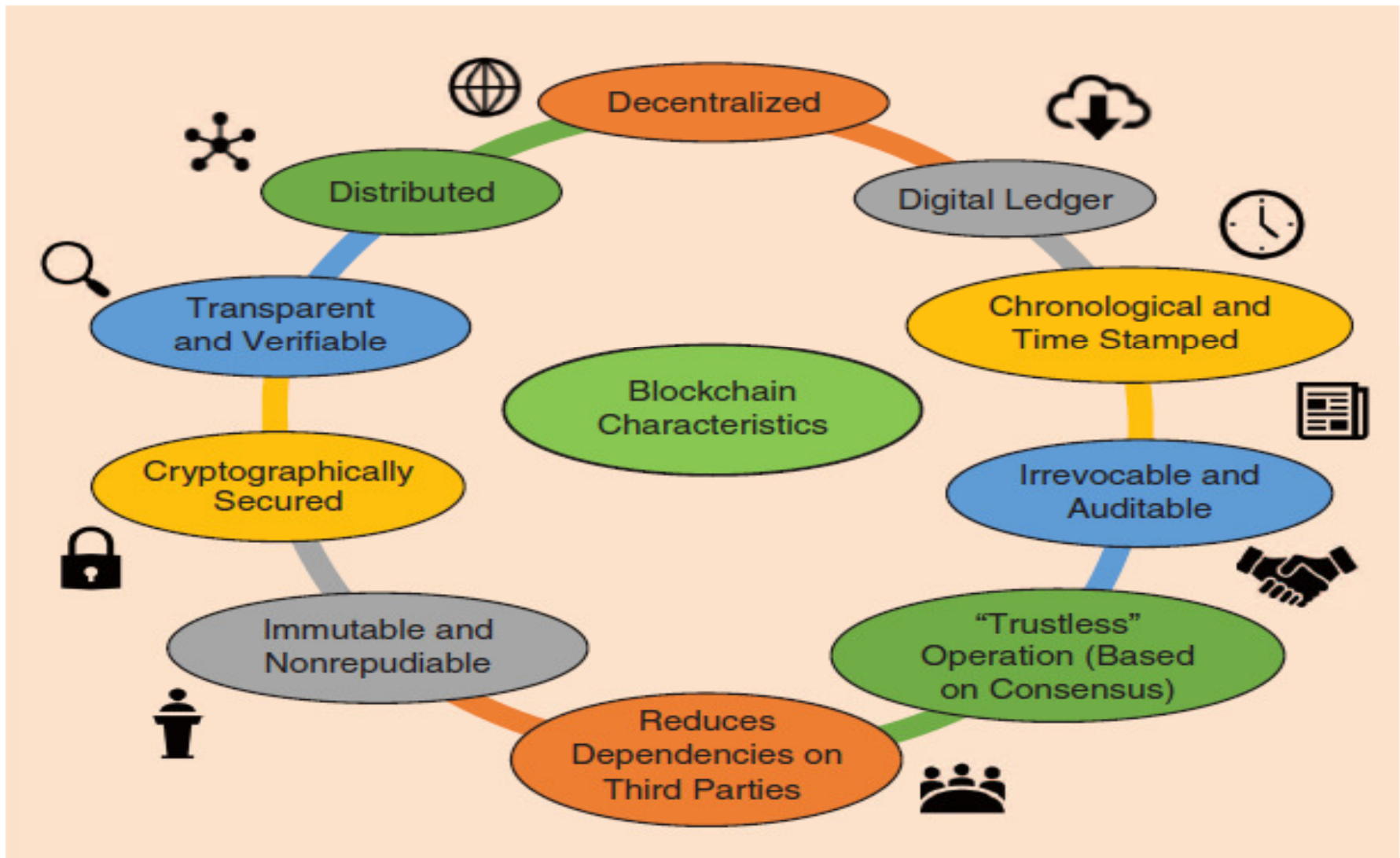
Crypto Currencies
are based on

[Blockchain Technology](#)

[Blockchain is a Distributed Ledger System](#)

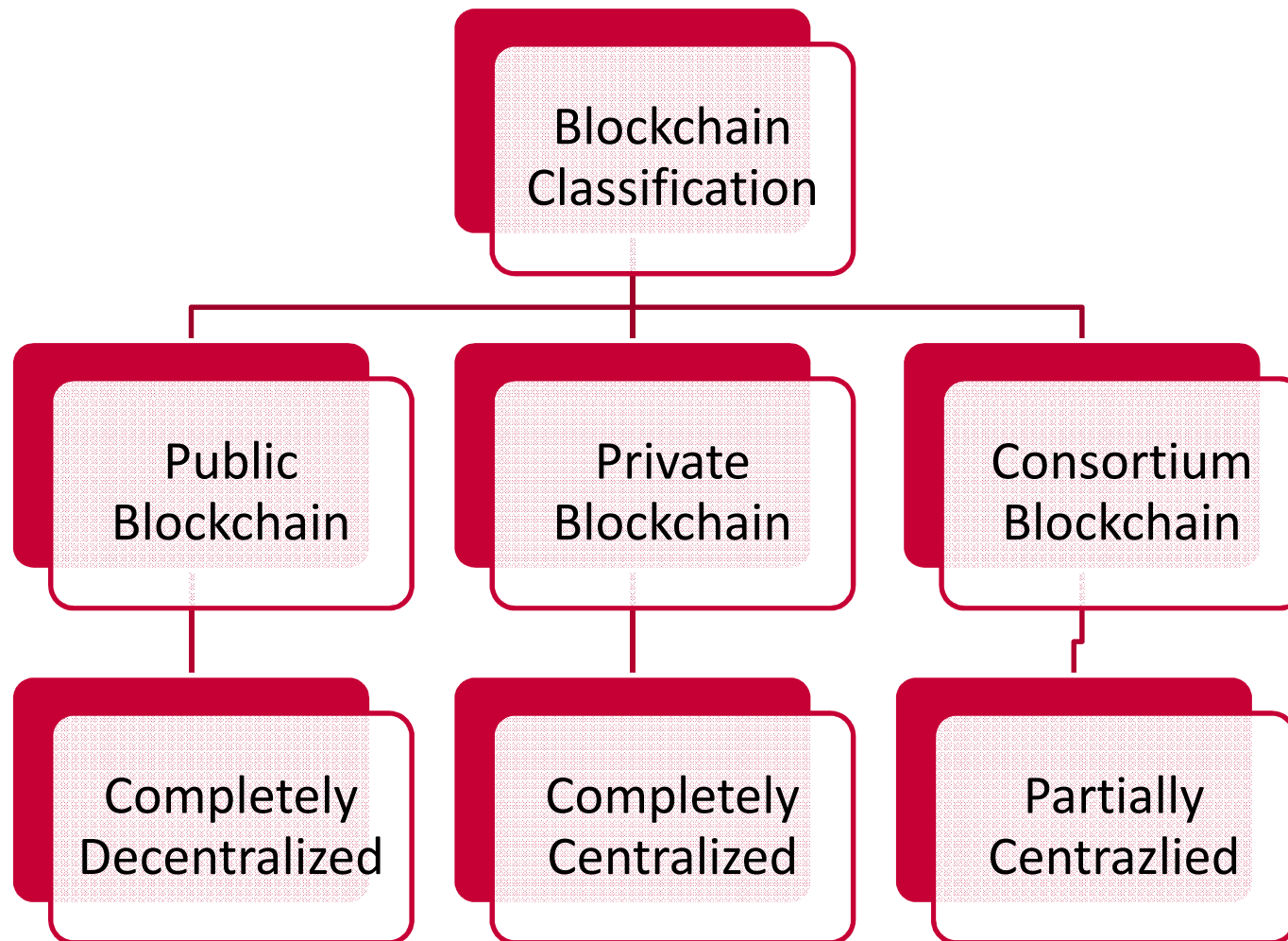
- A **blockchain** is a distributed ledger that is structured into a linked link of blocks. Each block contains an ordered set of transactions.
 - This distributed ledger is distributed across many machines.
 - Typical solutions use cryptographic hashes to secure the link from a block to its predecessor.
 - New transactions can be added, but old transactions cannot be deleted or modified.

Vital Characteristics of Blockchain



Source: The Blockchain as a Decentralized Security Framework, IEEE Consumer Electronics Magazine, 2018.

Classification of Blockchains



Cognitive Radio Networks and Blockchain Technology

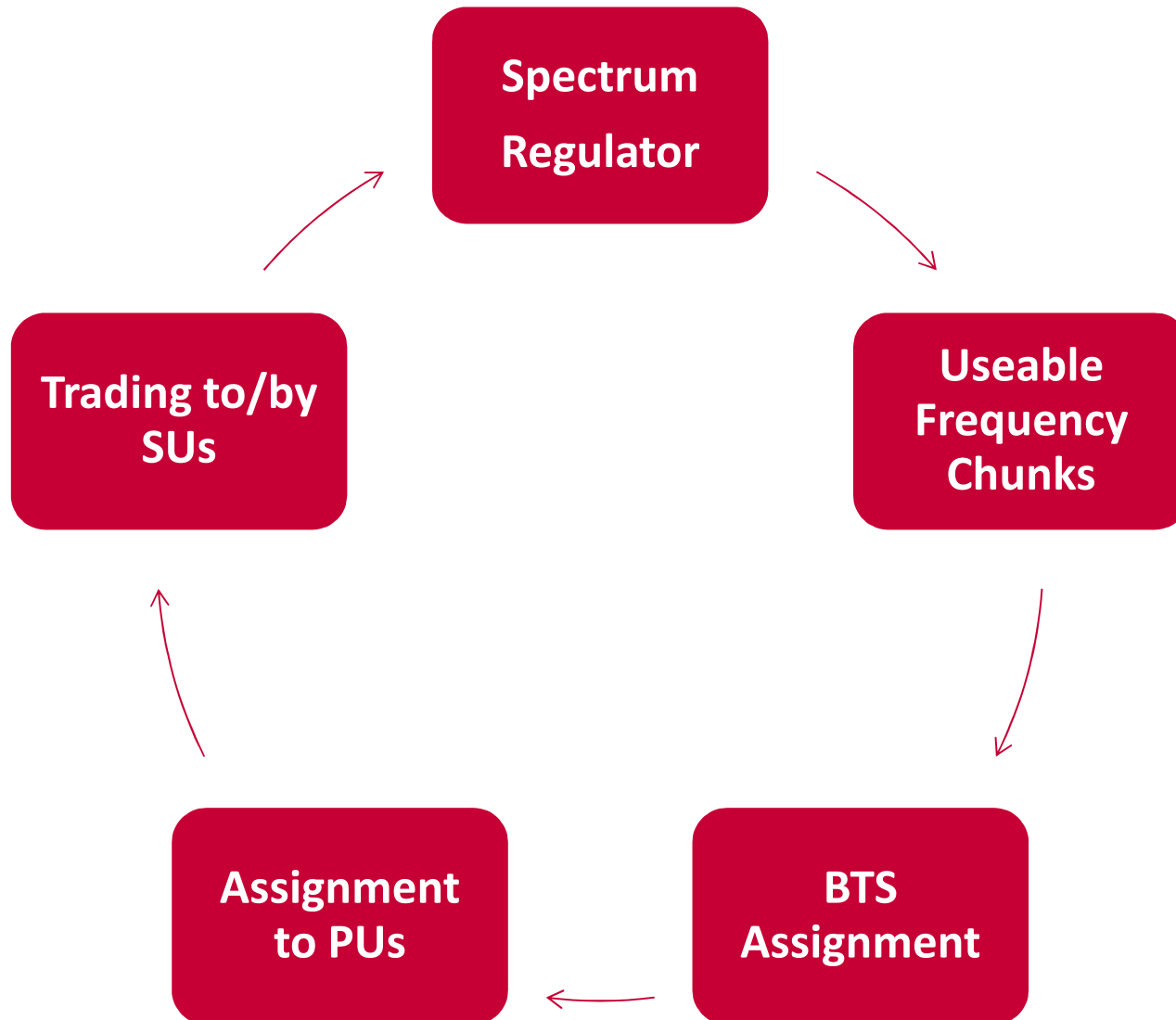
Wireless Radio Spectrum is Natural Resource!

Wireless Radio Spectrum is an Asset!

- Blockchain can help to establish
 - Trust among different organizations
 - Managing and involving in the spectrum regulation including spectrum sharing and trading market.

- It can also help to store data related with the complete life cycle of spectrum management i.e., from
 - Spectrum regulation,
 - Spectrum management,
 - Spectrum sharing, and
 - Spectrum trading.

Tracking of Wireless Radio Spectrum



- Smart contracts can revolutionize the spectrum trading process.
- With smart contracts, several new business models for spectrum trading can now be realized.
- Future trading of spectrum can now be possible upon completion of a certain condition.
- Can reduce the business process time.
- Make the system more autonomous by removing the dependency to different entities involved with this spectrum management life cycle.

Spectrum Trading for Short Period of Time



- Consider the availability of spectrum in terms of time.
- Traditionally, spectrum can be traded only for duration of:
 - Months, weeks, and days.
- Now it can also be sold on short periods of time, such as:
 - Hours, minutes, and even seconds.
- This new paradigm of spectrum trading of very short periods of time will:
 - Enhance spectrum utilization
 - Improve the revenue generation.

References and Further Reading



- C. Sengul, "[Distributed Ledgers for Spectrum Authorization](#)," in IEEE Internet Computing, vol. 24, no. 3, pp. 7-18, 1 May-June 2020.
- M. B. H. Weiss, K. Werbach, D. C. Sicker and C. E. C. Bastidas, "[On the Application of Blockchains to Spectrum Management](#)," in IEEE Transactions on Cognitive Communications and Networking, vol. 5, no. 2, pp. 193-205, June 2019.
- S. Bayhan, A. Zubow, P. Gawłowicz and A. Wolisz, "[Smart Contracts for Spectrum Sensing as a Service](#)," in IEEE Transactions on Cognitive Communications and Networking, vol. 5, no. 3, pp. 648-660, Sept. 2019.
- K. Kotobi and S. G. Bilen, "[Secure Blockchains for Dynamic Spectrum Access: A Decentralized Database in Moving Cognitive Radio Networks Enhances Security and User Access](#)," in IEEE Vehicular Technology Magazine, vol. 13, no. 1, pp. 32-39, March 2018.

Thanks

Questions?