Cognitive Radios for Unlicensed WANs

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A New Wireless Paradigm (1)

- There are several successful examples of wireless technologies.

1. Cellular (WANs):
   - Licensed spectrum.
   - Companies pay tremendous amounts of money for access to spectrum.
   - Base station controls traffic via a private control channel.
   - Highly regulated and scheduled traffic.
   - Additional spectrum maybe tough to obtain (time or expense).

2. Wireless LANs (WLANs):
   - Unlicensed spectrum.
   - No fee to use spectrum $\Rightarrow$ significant reduction in up-front business investment.
   - CSMA/Collision Avoidance contention access schemes.
   - Potentially high overhead associated with such access schemes.
   - Potential hidden nodes problems.

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A New Wireless Paradigm (2)

- For the new unlicensed spectrum based on cognitive radio techniques, we can combine the best attributes of licensed and unlicensed technology to create a new wireless paradigm.

- Goals for this new technology, referred to as Unlicensed WAN, are:
  - To achieve very high data rates.
  - Seamless network access.
  - Mobile data services.
  - Convenient roaming across networks (vertical handover).

- Will help drive the development of new wireless capabilities.

- Unlicensed spectrum will help:
  - Reduce costs.
  - Streamline the wireless business.
  - Open service to new segments of the population.

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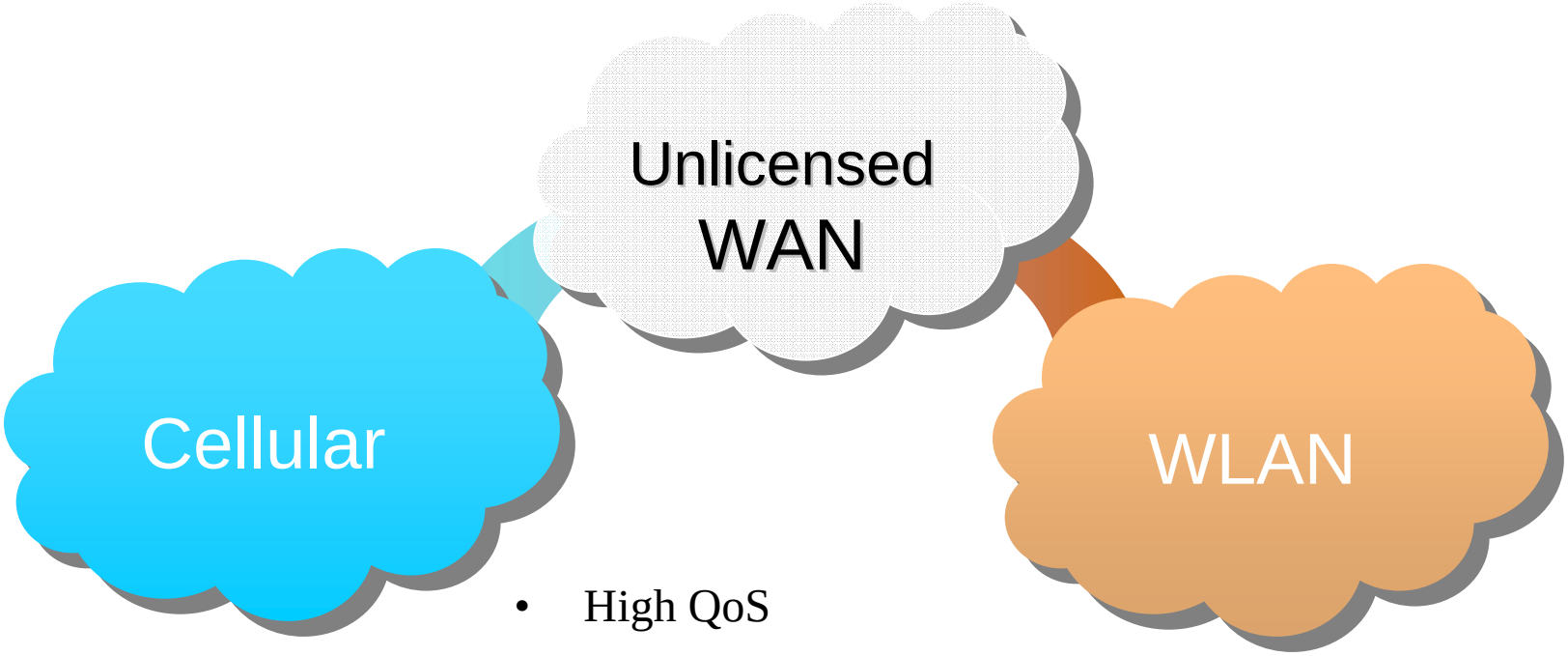
A New Wireless Paradigm (3)



- High QoS
- Reach a New User Segment
- Wide Area Coverage
- Transition from Cellular

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Benefits of Unlicensed WAN

- No spectrum cost or need to obtain licenses:
  - Significant reduction in up-front business investment.
  - Competitors can easily enter market at any time.
  - Private systems can be supported offering low/no cost service.
- Spectrum remains in public domain.
- Future system upgrades, technology migration can be simple to deploy. Also ability to easily deploy private systems.
- Peer-to-peer calling benefits rural areas and possibly low income users.
- System infrastructure provides framework for temporary/shared spectrum, online spectrum bartering, and unlicensed spectrum access.
- Consistent with FCC Spectrum Policy Task Force Report's recommendation for "commons", unlicensed spectrum.

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Key Aspects of an Unlicensed WAN

- Just like today's cellular services, but operationally different:
  - Session setup mechanism is shared.
  - Spectrum is shared, database via ARM provides spectrum availability.
- Available Resource Map (ARM):
  - Provides real-time view of available system resource.
  - Resources could be freely available, shared temporarily, or for sale.
  - Temporarily available spectrum can be rapidly returned to primary user.
  - Normally provided over a wired communications link (WCC).
- Explicit control of session setup:
  - Conventional CSMA/CA may not be efficient for wide area systems.
  - Allows deployment of very high-performance modulations.
  - Takes advantage of precise user position information.
  - Uses shared radio control channel (RCC) for all system users.
- Various levels of functionality/features are possible.

System Control

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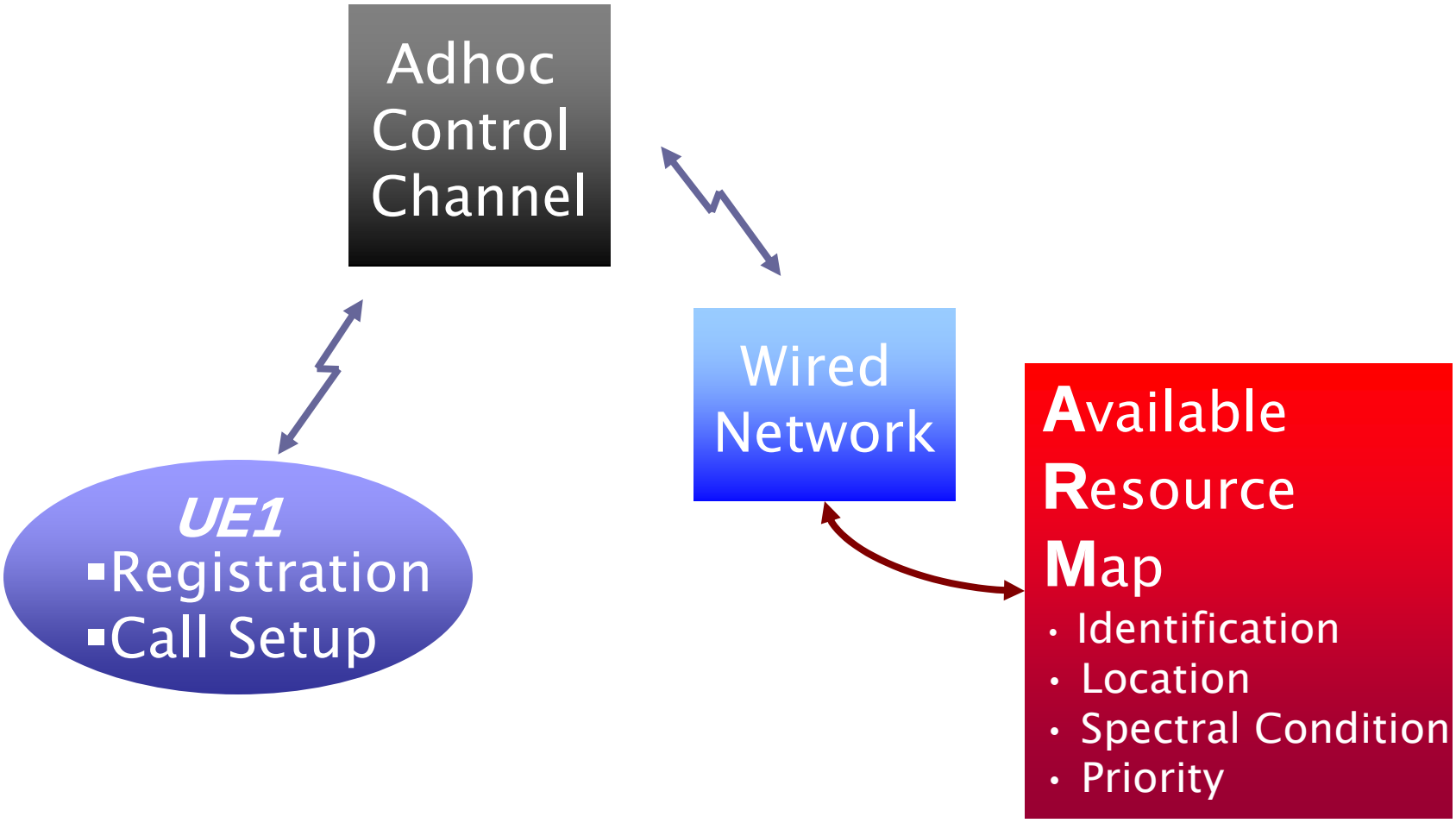
Distributed Resource Control: UE to BS



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Available Resource Map

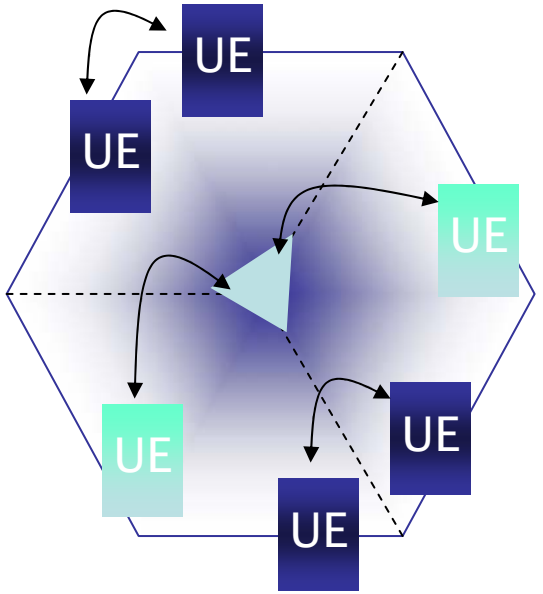
- Available Resource Map (ARM) enables many users to share non-exclusive spectrum:
  - Accessed via Wired Control Channel.
  - Via Cellular Base Stations or other Access Points.
  - Enables spectrum to be shared, leased.

- A publicly accessible database:
  - Accurate, real-time map of spectral condition.
  - Geographical.
  - Multi-dimensional, contains user attributes such as UE capability, user's system priority.

- Advantages of ARM:
  - Since spectrum is shared, all spectrum is available to all base stations: eliminates problem that one provider is out of spectrum, while another has idle resources.
  - Spectrum management is more sophisticated.
  - Spectrum re-use not artificially limited to cell sites or sectors.
  - Provides real-time view of what spectrum is available at all times.

System Operation Modes

- UE to BS:
  - Identical to present cellular system, except the Available Resource Map (ARM) is known publicly, updated by BS.
- UE to UE (pedestrian speeds):
  - UEs negotiate a common channel.
  - If within a BS cell, BS monitors their agreement.
- UE to UE (mobile speeds):
  - UEs negotiate a common channel.
  - Within reasonable range, UEs can travel together.
  - Monitor Ad Hoc control channel (RCC) frequently.



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Distributed Resource Control (1)

UE to BS via Ad Hoc Control Channel

- Registration:
  - Upon power-up, UE sends request to register on un-licensed ad hoc paging channel (RCC), a specific frequency/code for this location.
  - BS acknowledges UE on ad hoc channel.
  - UE sends identification, position, spectral conditions (usage) info to BS, who passes info to ARM.

- Request for call initiation – outgoing call:
  - Active user (UE1) requests call assistance from BS.
  - Network determines location of UE2.
    - Is it active?
    - Can it be located?
    - Is it capable of unlicensed communications via ARM?
  - Link is set up in normal cellular manner:
    - UE1 → BS → (BS2) → UE2.

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Distributed Resource Control (2)

UE to BS via Ad Hoc Control Channel

- Answering a page – incoming call:
  - BS knows position of active user (UE1).
  - Page sent to UE1 using ad hoc control channel.
  - Link is set up in normal cellular manner.
    - UE1 → BS → (BS2) → UE2

Wireless Link Setup (1)

UE to UE

- Peer-to-peer communications.
- UE1 polls ad hoc control channel (RCC) for UE2:
  - If UE1 and UE2 are within same BS:
    1. Within range, they exchange spectral conditions.
    2. Agree on common spectrum.
    3. Base station monitors, updates local ARM, works around them, spectrum freed for other BS users.
    4. Reserved in ARM for UE1 and UE2 based on combined priority.
    5. If UE moves out of handset range:
       - They call the BS and request assistance.
       - BS accepts and provides both links.
       - They are now cellular, if subscribers.

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Wireless Link Setup (2)

UE to UE

- UE1 polls ad hoc control channel (RCC) for UE2:
  - If UE2 is within range of UE1, but no access to BS:
    1. They exchange spectral conditions based on monitoring local spectrum usage.
    2. Over RCC, they agree on common spectrum.
    3. Both devices report their intention (location of each user, intended power level, and spectrum).
    4. All handsets constantly monitor RCC.
    5. If other users would suffer from interference, they must OBJECT to the new session over the RCC.
    6. If there is an objection, the peers must look for spectrum elsewhere.

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Peer-to-Peer Communications

- Clear that Peer-to-Peer communications can be rather cumbersome.
  - Complex setup.
  - No access to ARM.
  - Range is limited.
- Applications:
  - Extended cordless phone service.
  - Walkie-talkies.
- Benefits:
  - Robust to equipment failure, such as loss of base station or loss of ARM.
  - Effective in rural areas, where coverage is limited or persons cannot afford regular service.
  - Relaxes the need for service provides to be required to serve remote areas where financial returns are not possible.

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Peer-to-Peer Communications: Rural Areas

- Mode enables coverage of very low density regions over long distances.
- Allows carriers to fulfill all-digital conversion in 2007:
  - Sep 2002 FCC ruling for 5-year analog ‘sunset’.
- Users can enhance their range by purchasing a simple high-power UE (private base) station:
  - For home or vehicle.
  - Enables high-powered transmitter away from user’s body.
- Frequency allocation in rural areas:
  - Uses lowest frequencies available (allocated) for furthest distance.
  - Allocation could also use GPS location to determine frequency/code scheme, creating virtual cells.
  - Knowing location, UEs monitor known adjacent frequencies based upon algorithms (variable area), or grid-based.

Potential Issues

Spectrum Management?

- Pros:
  - Hallmark of cellular system: base station manages local, exclusive frequency allocation
  - Common factor in high QoS systems
  - Prevents collision before it happens, no interruption

- Cons:
  - ‘Set-up time’ required before using system
  - Periodic monitoring of spectrum, ARM parameter updates

Or Interference Mitigation?

- Pros:
  - Interference Mitigation does not require a central controlling authority.
  - Physical link designed so that interference can be suppressed.

- Cons:
  - A big problem in long-range WANs, due to the number of users in an environment.
  - Requires limitation on possible interferers: Bandwidth, Modulation, etc.
  - Inherent interruptions lead to poor QoS (dropped calls, halted audio & video, jitter).

Areas for Development

- Ad Hoc Control Channel:
  - Contention similar to WLAN access.
  - CSMA/CA protocol/etiquette resolves collision with random re-transmit delay (ALOHA-like).
  - All devices utilize GPS time for synchronization.
  - ACK/NAK used for handshake.
  - Minimize monitoring while UEs keep up with networked ARM, maybe as often as once per second.
  - Message received by UEs when another link contends for their resource area/spectrum.

- Available Resource Map:
  - Geographical reservation based upon:
    - What spectrum is available for system.
    - Then, upon what spectrum is not presently used.
  - Local spectral conditions (usage) at each UE (Interference Temperature).
  - Long Distance, running over intra-link users (road kill).
  - Priority, who gets what, duration of wireless link, etc.

User Priority

- Since spectrum access is free, a policy is needed to ensure fair access.
- Entities controlling spectrum could be given top priority for use, encouraging more spectrum to become available (i.e. the military, police, etc.
- User priority can be simply controlled by giving those with minimal recent use top priority.
- Users who desire guaranteed access can subscribe to services offered with licensed spectrum.

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Major Role for Today's Operators

- Unlicensed spectrum provides many key business opportunities for incumbent operators:
  - Incumbent operators can readily provide mobility support through wired control infrastructure and session handoffs (no handoff capability in a peer-to-peer session).
  - Provide vertical handoffs to other networks.
  - Nation-wide and/or world-wide registration allows incumbent operators to easily locate and place calls to subscribers.
  - Existing networks offer nationwide coverage to customers.
  - Air interfaces can be designed so that incumbent operators can provide full regional coverage with existing towers.

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What level of Regulation is Needed?

- One approach:
  - Spectrum must be channelized, in-band/out-of-band power levels set, and allowed modulations specified.
  - Protocol/Etiquette for control channels and user priority scheme must be established.
  - Temporarily available spectrum must be “posted” over the control channels (duty could fall to primary user).
  - Equipment must meet mandates for appropriate use and adhere to required protocols and user etiquette (independent testing labs could be used)
  - Radio certification: certify once and radio adapts to local environment.

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A Great Way for Us to Utilize Spectrum

- Maximizes free competition and economic efficiency:
  - Clearing house for sale, barter, temporary, and free spectrum use.
  - No limitations on operators to expand business, enter markets, etc.
  - Lowers cost to enter business, dramatically reduces bureaucracy.
- Spectrum (unlicensed) remains a public resource:
  - Technology upgrades can be phased in over time to ensure best possible use.
- Innovation is rewarded:
  - Most flexible products with best technology offer users best service and performance.
- Wireless links are relatively short range, operators and users are rewarded for getting on nearest wired backhaul.
- System provide service to all levels of society, rural users, disadvantaged persons, etc.

Unlicensed WAN Summary

- Unlicensed WANs operate very similarly to today's cellular systems, but make use of an Available Resource Map (ARM) and an ad-hoc radio control channel (RCC).

- Extension of cellular concept, except for:
  - Session setup mechanism is shared.
  - Spectrum is shared.
  - ARM provides real time spectrum availability

- The ARM allows sharing of unlicensed spectrum, temporarily available (shared) spectrum, and licensed spectrum.

- Unlicensed WANs maximize free competition, reward technical innovation, and provide a peer-to-peer mode to benefit rural and disadvantaged persons.