Nationwide Capacity of a Digital Air/Ground Radio System for Air Traffic Services

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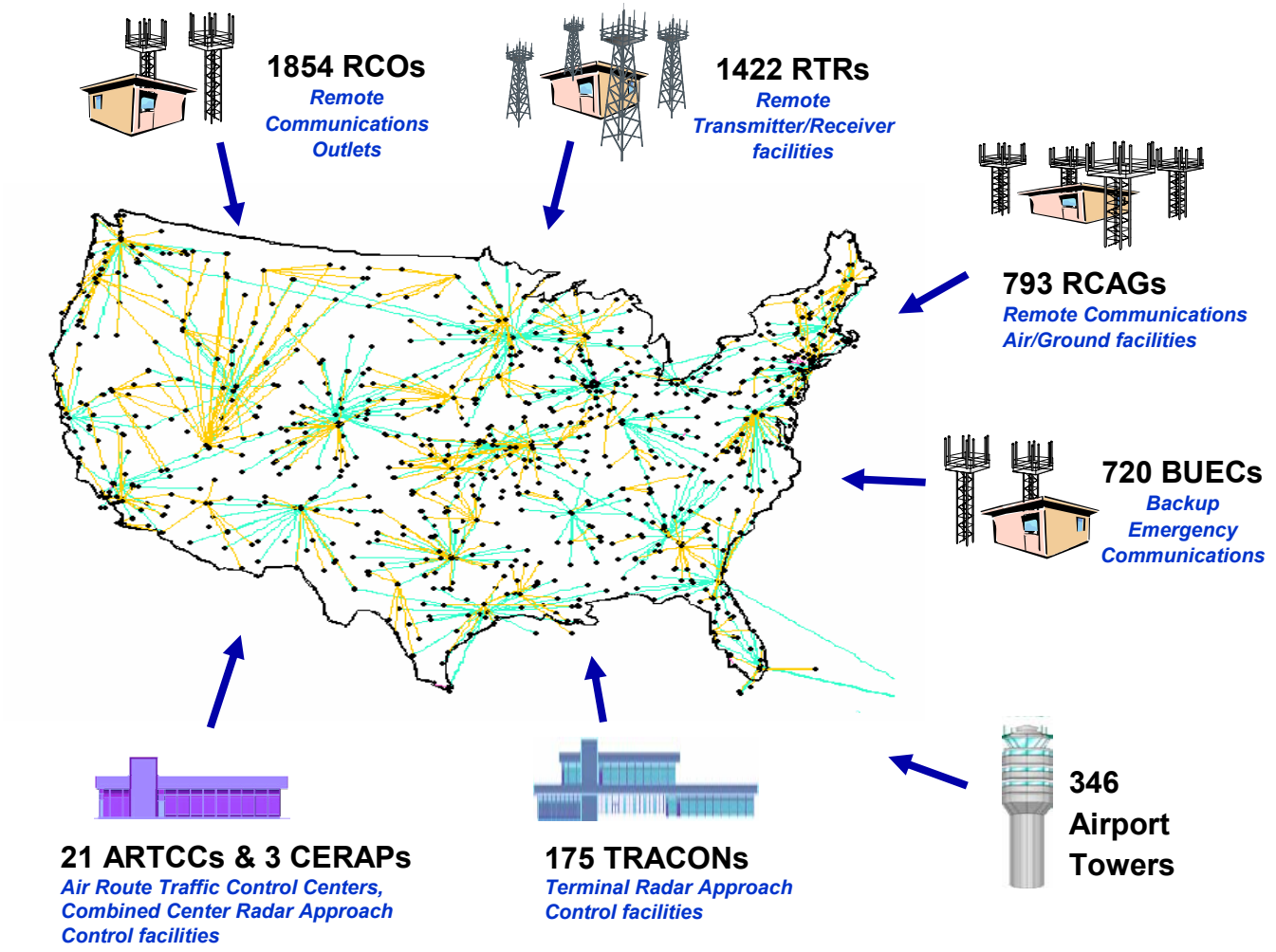
Introduction

- **Radio-frequency (RF) spectral congestion limits the capacity of the VHF air/ground (A/G) radio system for air traffic services (ATS)**
- **Planned upgrade to VHF Digital Link Mode 3 (VDL3) will increase system capacity**
- **The transition to VDL3, and subsequent system growth, can be managed in a way that will tend to maximize the resultant capacity gain**

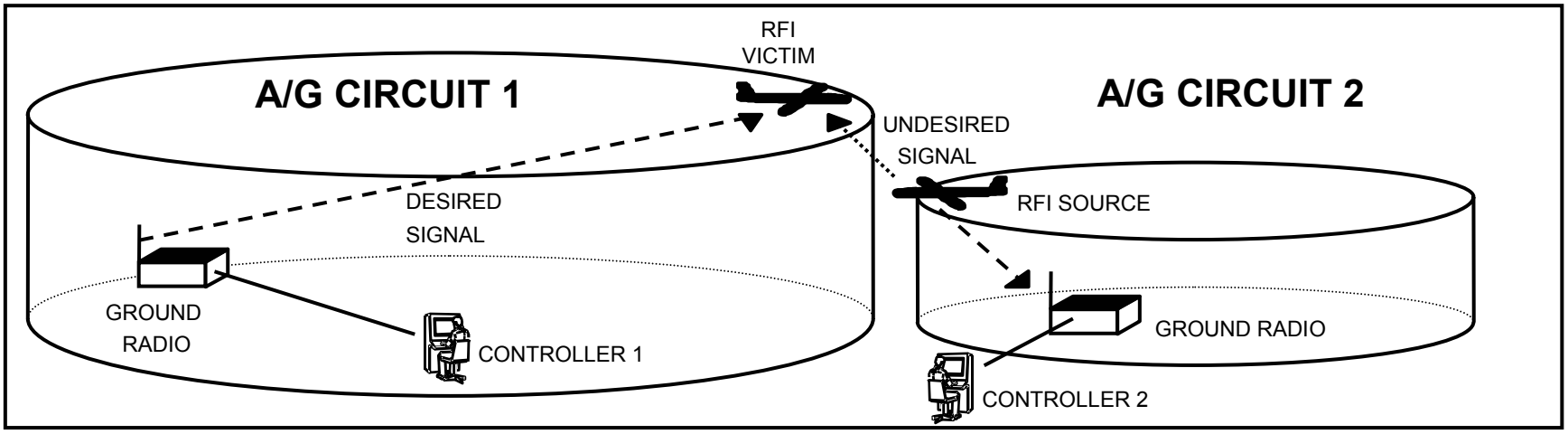
VHF Air/Ground Radio System for ATS

Today's A/G radio system for ATS:

- Provides voice ATC communication between controllers and pilots
- Also supports ATIS/AWOS/ASOS voice uplink broadcasts to pilots
- Comprises roughly 6,700 separate circuits in U.S. airspace
- Uses ≈511 of 720 distinct frequencies in the 118–136 MHz band



How RF Interference (RFI) Limits the Capacity of the Existing A/G Radio System



- **A/G circuits must be separated in <u>distance</u> or <u>frequency</u> to avoid RFI**
  - **If service volumes (SVs) are not mutually visible, or undesired signal path is at least 5 times as long as desired path, circuits can <u>share</u> a frequency**
  - **If SVs are too close for frequency sharing but do not touch or overlap, the circuits can usually operate on "adjacent" frequencies (25 kHz apart)**
  - **If SVs < 0.6 nmi apart, circuits must operate at least <u>50</u> kHz apart**
- **<u>Nationwide capacity</u> of existing system is total number of needed ATS circuits the system can support without violations of the above rules**

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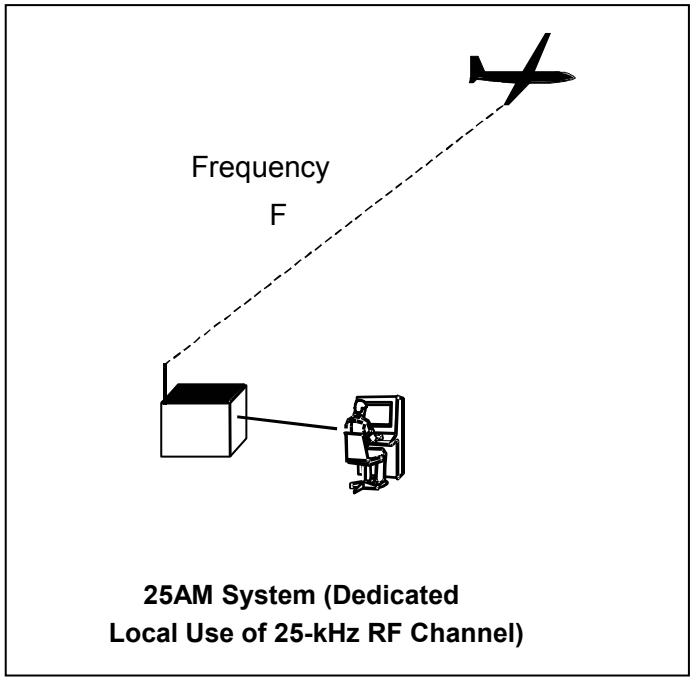
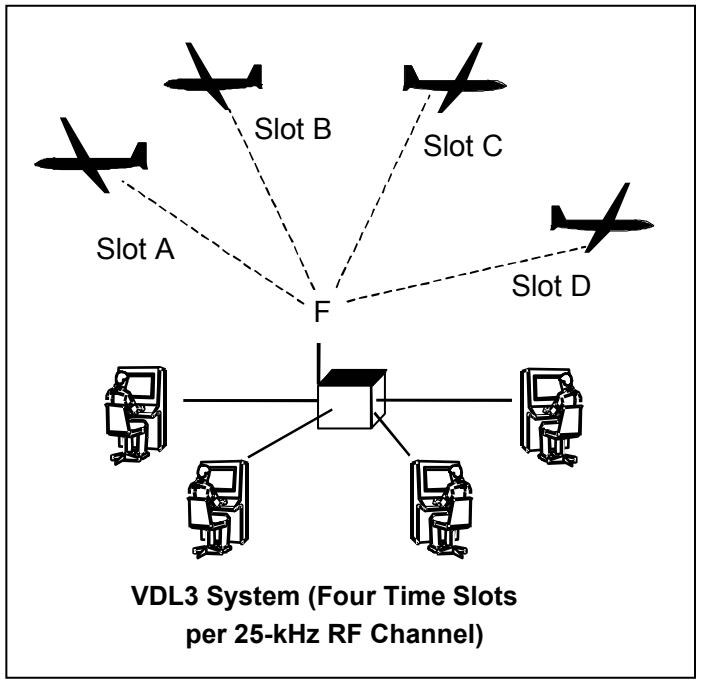
System Channelization



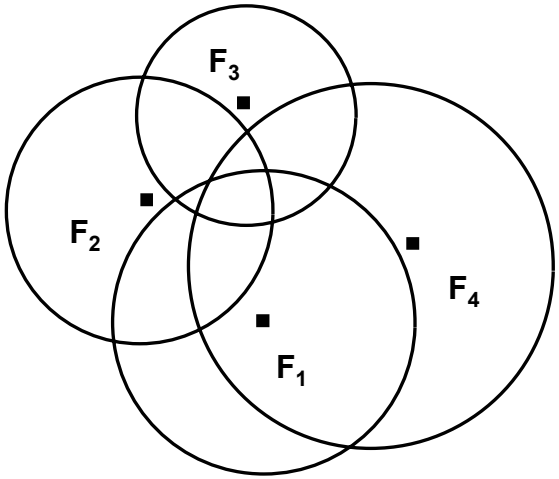
25AM System (Dedicated Local Use of 25-kHz RF Channel)



VDL3 System (Four Time Slots per 25-kHz RF Channel)

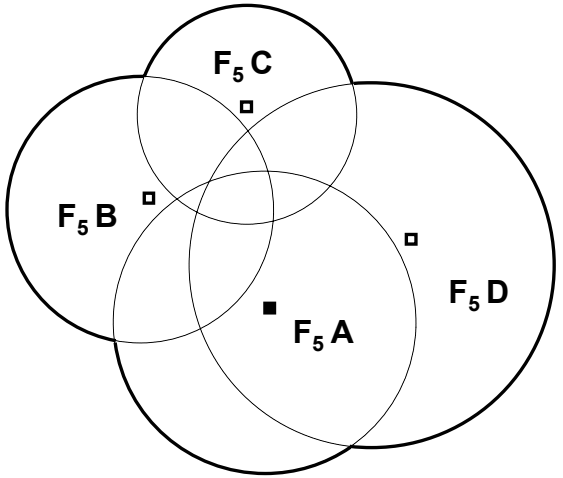
- Existing "25AM" system uses AM in 25-kHz channels
- VDL3 uses TDMA to increase capacity
  - 4V configuration provides 4 voice slots
  - 3V provides only 3 voice slots, but longer guard times
  - Other configurations provide mixes of voice and data slots

Forming a VDL3 Bundle



Before Conversion to VDL3:

- 4 A/G radio circuits
- 4 primary ground radios (squares)
- 4 frequencies (F_1, F_2, F_3, F_4)



After Conversion to VDL3:

- The 4 circuits form a TDMA *bundle* on one frequency (F_5)
- Circuit on slot A is designated the *host*
- Circuits on slots B, C, and D are *guests*
- Guests may retain own ground radios or share that of host

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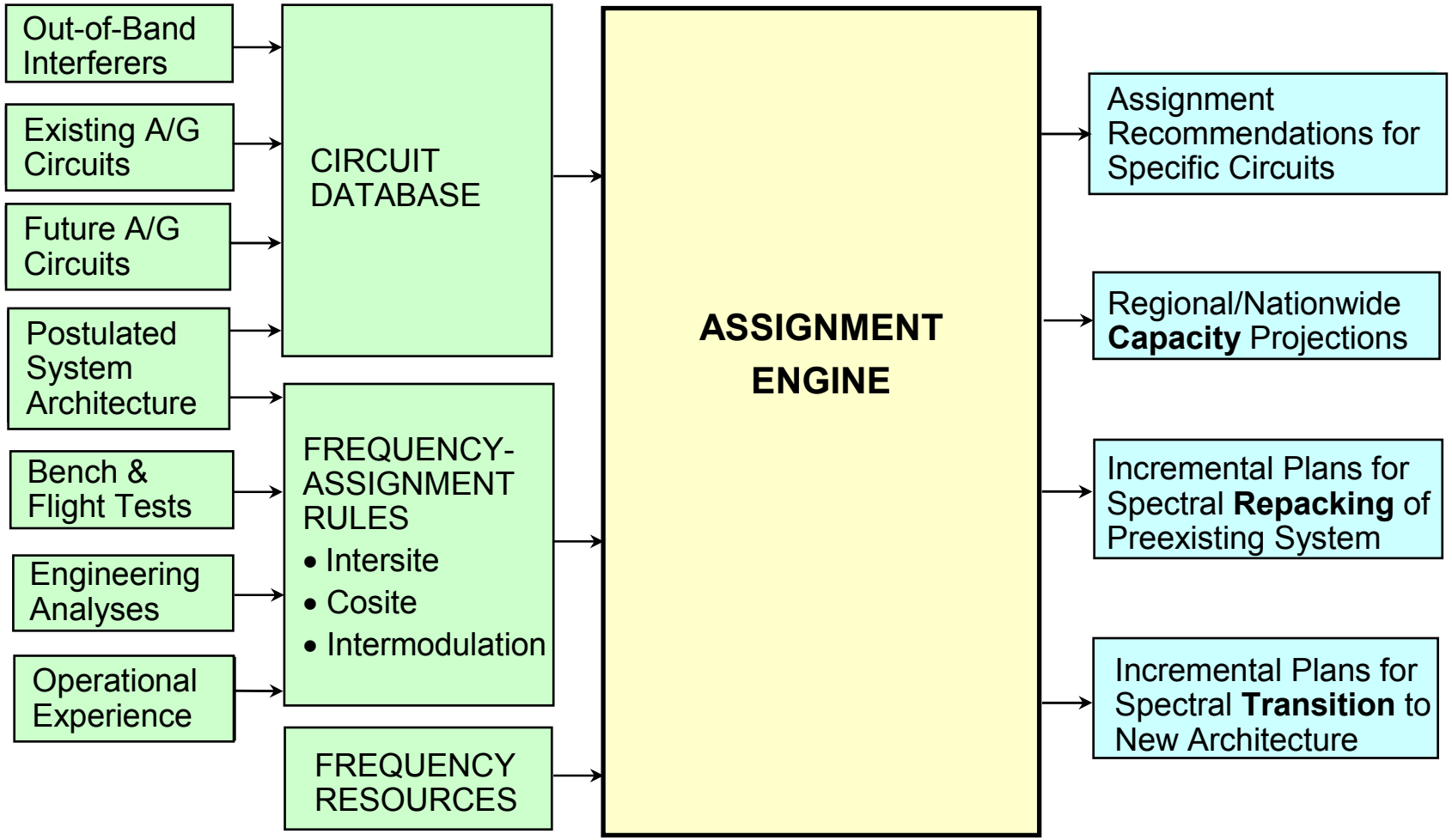
The 25AM-to-VDL3 Transition

- **New intersite RFI-prevention rules (still being developed) will affect the transition**
  - **Minimum undesired/desired distance ratios for cochannel circuits**
    - **5:1 (14-dB) rule still holds when both circuits are 25AM**
    - **10:1 (20-dB) rule is assumed in our simulations for VDL3-to-VDL3 cases**
    - **32:1 (30-dB) rule is assumed for VDL3-to-25AM cases**
    - **Radio horizon greatly mitigates impact of the increased ratios**
  - **Circuits with overlapping SVs may have to stay 75 to 125 kHz apart, depending on whether both are VDL3 or one is still 25AM**
- **Consequently, most circuits will need to change their frequencies when converted to VDL3**
  - **"Neighbor-repacking" (selective changes to neighboring circuits' frequency assignments) also needed sometimes**

Spectrum Prospector™: An Automated Frequency-Planning Tool for A/G Radio System Evolution



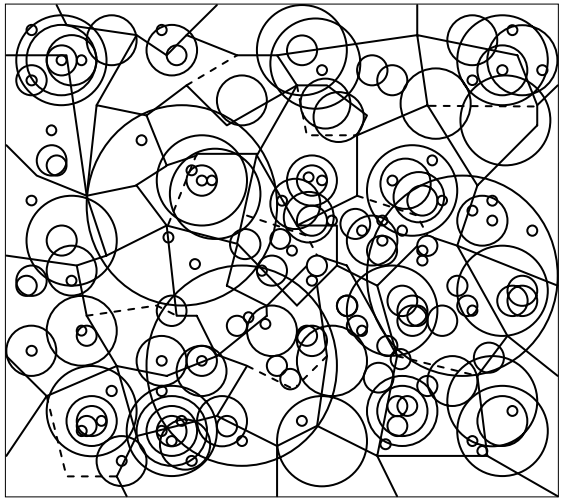
Estimating Nationwide Capacity

- **Scenarios**
  - **Continued exclusive use of 25AM**
  - **Incremental ATS transition to VDL3**
- **Approach: Use Spectrum Prospector to see how many circuits can be added in each scenario before an unavoidable "frequency denial" occurs**
  - **Simulate "random *proportional* growth" of ATS circuit population**
  - **Add hypothetical new circuits one by one to actual circuit database**
  - **Find violation-free frequency for each new circuit when it appears**
  - **Repeat simulations 10 times with different random "circuit arrival" orders**
- **Assumptions**
  - **524 frequencies available for ATS**
  - **Only *intersite* (cochannel and adjacent-channel) assignment rules matter when estimating nationwide capacity**
  - **Cosite and intermodulation problems assumed solvable by filtering or resiting**

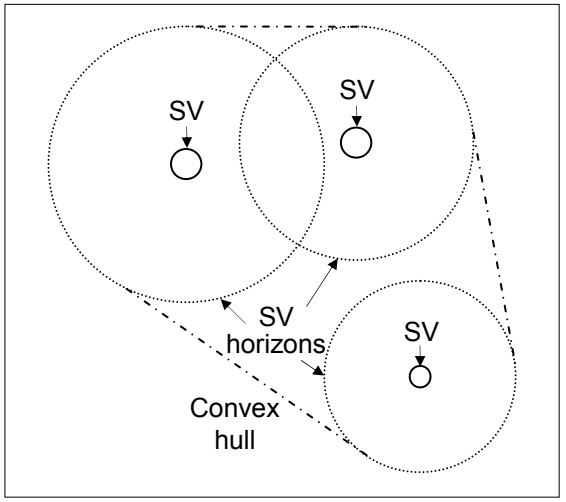
Spectral-Efficiency Heuristics

- **25AM and VDL3 scenarios:**
  - **Use lowest available violation-free frequency (if there are any)**
  - **"Neighbor-repack" as necessary to make spectral room for new circuits**
- **VDL3 scenario only:**
  - **Form 4-slot instead of 3-slot circuit bundles whenever feasible**
  - **Keep bundles compact**
    - **Radio horizons of all SVs in a bundle should coincide as nearly as possible**
    - **Side benefit: Fewer frequency changes needed for 25AM-to-VDL3 transition**
  - **Try to fill all slots in most bundles, before starting new ones**
  - **Keep some slots open in "large-horizon" bundles, to leave room for future hard-to-fit en route circuits**
  - **Disassemble already-formed full bundles when necessary to free up a slot for an otherwise unassignable new circuit ("neighbor-rebundling")**

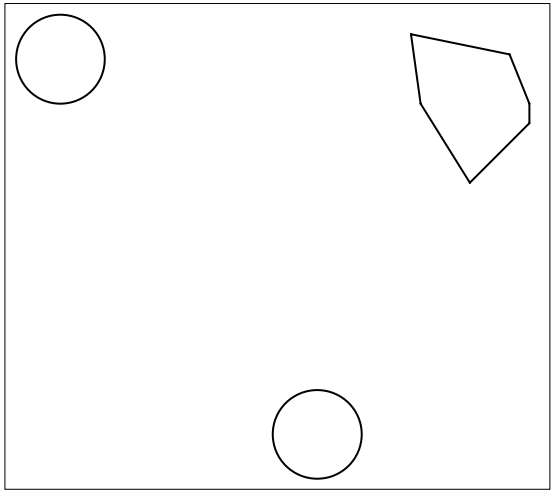
Forming Compact VDL3 Bundles



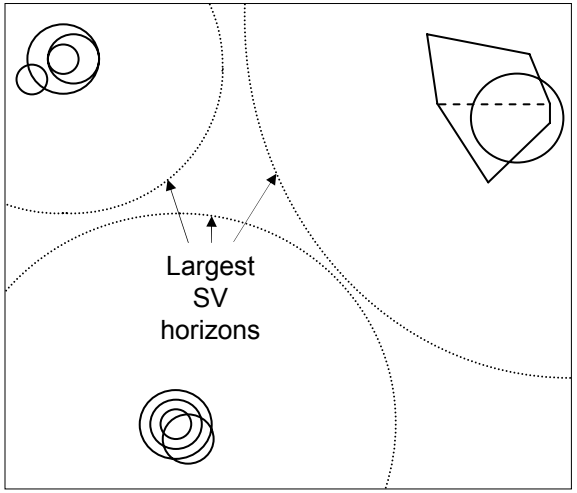
(a) Plan View of Circuit SVs



(b) Bundle Compactness = (Average Horizon Area) / (Hull Area)



(c) Very Loose 3-Slot Bundle (Poor Spectral Efficiency)



(d) 4 Cochannel 4-Slot Bundles in Same Area (Much Better Efficiency)

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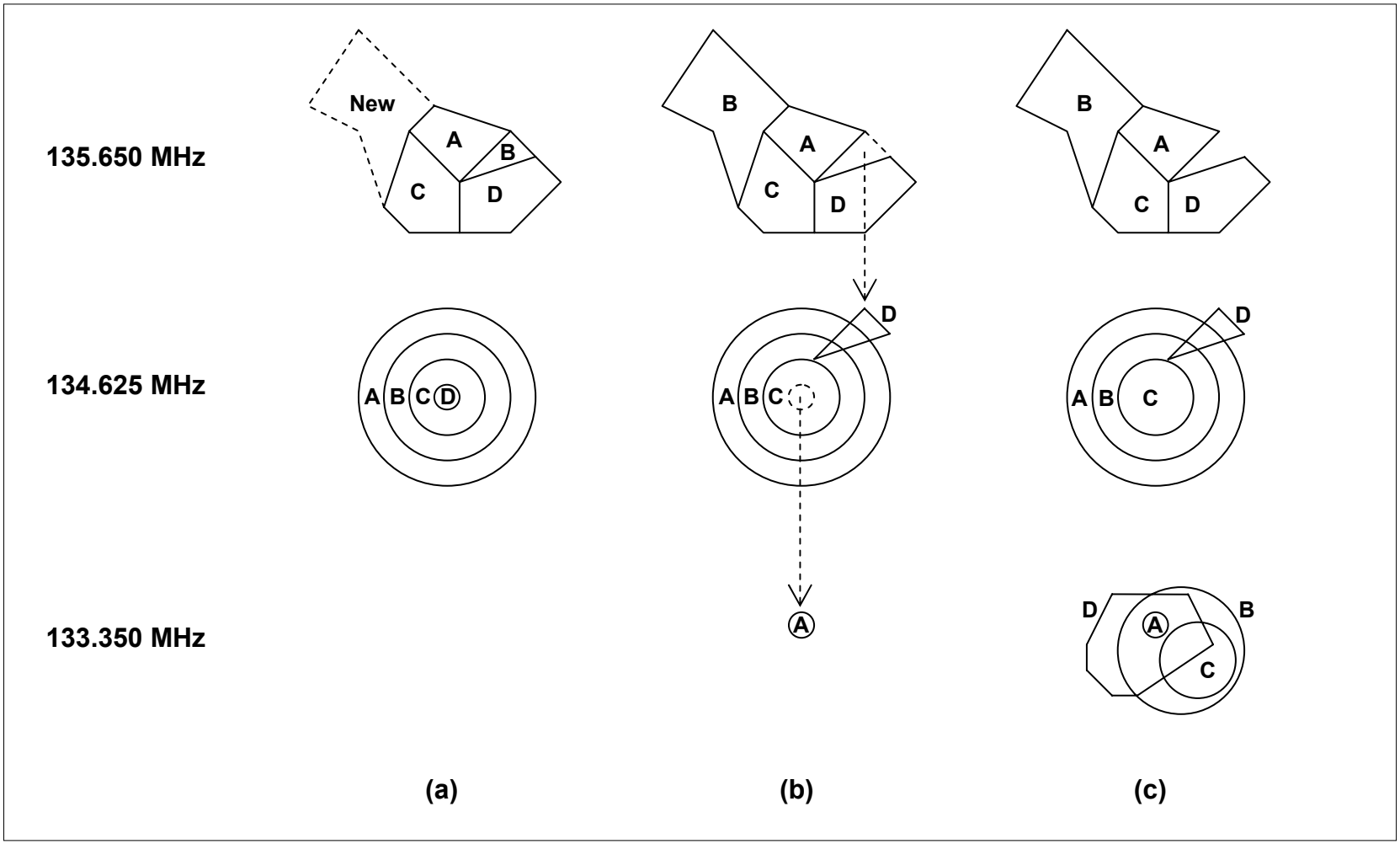
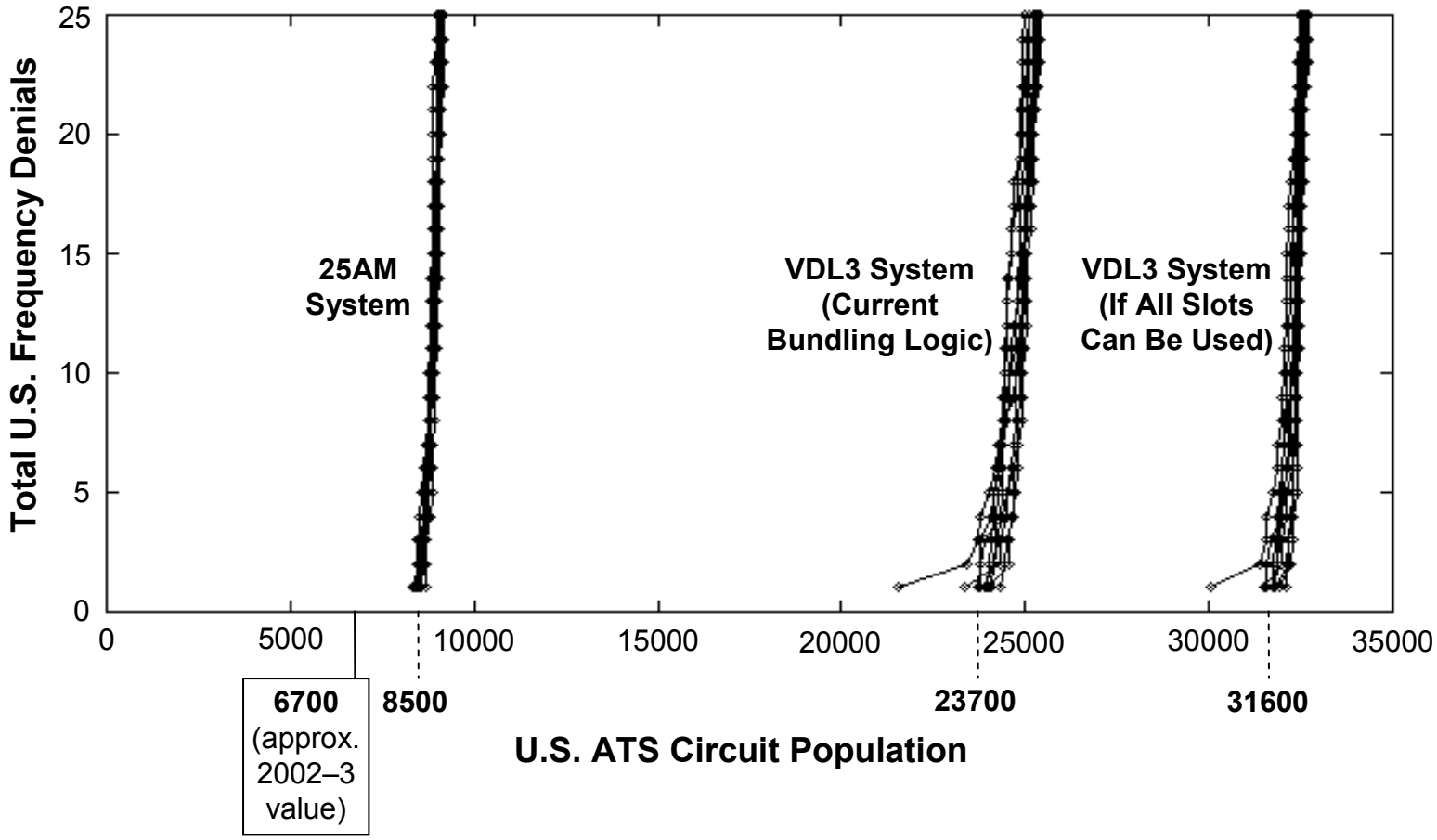
Example of "Neighbor-Rebundling"



Occurrence of Frequency Denials in 25AM and VDL3 Scenarios



Nationwide Capacities of Simulated Analog and VDL3 Systems

Scenario	Approx. Number of U.S. ATS Circuits at Time of First U.S. Frequency Denial			Mean Capacity Gain over 25AM System
	Minimum	**Mean**	Maximum	
25AM	8,300	**8,500**	8,700	**1.0**
VDL3 (Current Bundling Logic)	21,600	**23,700**	24,300	**2.8**
VDL3 (If All Slots Can Be Used)	30,100	**31,600**	32,100	**3.7**

(Actual number of U.S. ATS circuits in 2002–3 was about **6,700**.)

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Conclusions

- **Best measure of nationwide VHF A/G radio system "capacity" is the total number of circuits the system can support before first frequency denial**
- **If "proportional growth" assumption holds, 25AM system capacity ≈ 8,500 ATS circuits (about 25% more than 2002–3 circuit population)**
  - **Faster growth at high altitudes or in already-congested regions could substantially reduce capacity**
- **To maximize capacity, spectrally efficient heuristics should be used in VDL3 bundling:**
  - **Bundle compactness (also simplifies 25AM-to-VDL3 transition)**
  - **Saving some slots for future en route circuits**
- **Interim result: If efficient heuristics are used, capacity of future all-VDL3 system is at least 2.8 times that of 25AM**
- **Future algorithms may enable fuller slot utilization and eventually allow VDL3 capacity up to 3.7 times that of 25AM**