Wireless, spectrum scarcity, and expanding our notions of sharing….

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How will wireless evolve? Like wired, maybe?

Wired broadband is evolving to a common platform architecture

General purpose, fiber-rich, Everything-over-IP

Wireless broadband is evolving differently

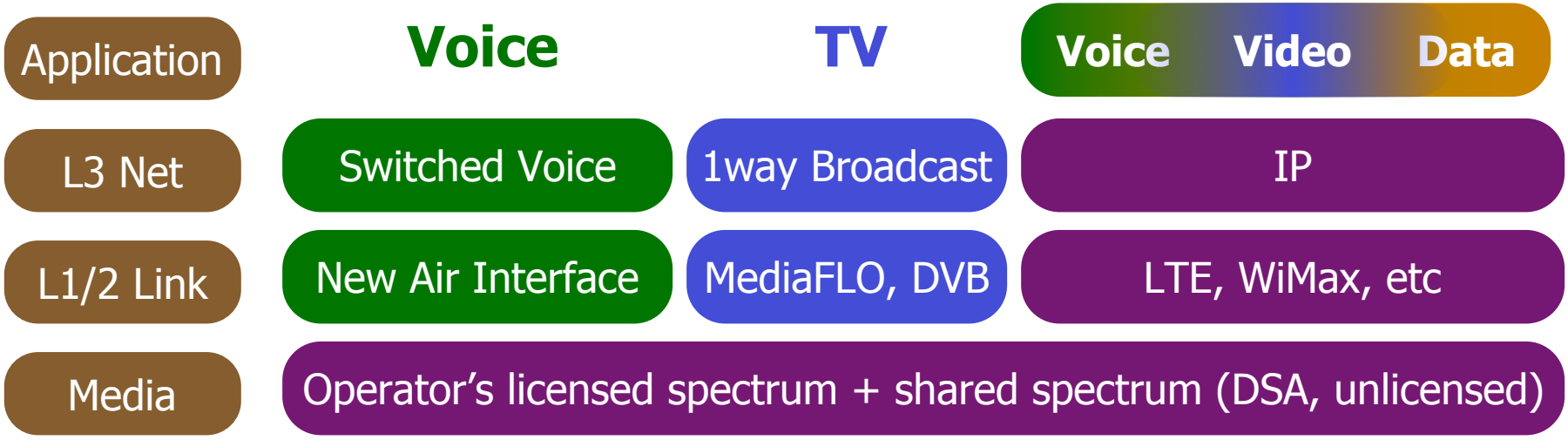
No single platform, due to persistent technical differences

Table 1 Persistent Key Differences in Wired vs. Wireless Networking		
	Wired	Wireless
Capacity	**Abundant**	**Scarce**
Topology	**Point-to-point**	**Broadcast**
Reliability	**Reliable**	**Unreliable**
Mobility	**Fixed**	**Mobile**

If wireless is not evolving *like* wired, then how will it evolve?

Key driver: spectrum scarcity…..

Hybrid Wireless Broadband



A single broadband service provider uses:

Hybrid wireless network types

Mix of application-specific networks and generic data networks

Hybrid spectrum rights

Mix of exclusive, shared, unlicensed, short-term leases, secondary, ...

Continuous spectrum reallocation

Among the operator's own networks and applications

Across independent operators/regimes via markets, private commons, ...

Why is the future of wireless broadband "hybrid"?

Current 3G service providers are already hybrid

Smartphones provide converged access to (e.g.)

Voice-specialized network	GSM
Generic data network	3G HSPA
Unlicensed spectrum	WiFi, Bluetooth, GPS
Network shared among operators	MediaFLO

(Spectrum sharing and reallocation is embyronic)

Prediction: this will continue **(LTE vision notwithstanding)**

Specialized networks are more spectrally efficient

Prediction: operators will not be able to acquire/afford enough exclusively licensed spectrum to meet demand

c.f. ITU-R wp8F M.2078, recent auction valuations

Spectrum sharing (of all types) will become critical for core services

Future is shared spectrum

aka "Dynamic Spectrum Access" (DSA)

decoupling of spectrum frequencies from applications (& *infrastructure)*

Domain	Trend is towards	Drivers and Enablers
Technology (capabilities)	Frequency agility Improved capability for spectrum sharing	Smart radio systems OFDM and spread spectrum Growth of fast data networks
Revenue (customer experience)	24/7 availability Simplicity of use Seamless mobility	Heterogeneous networks 3G+WiFi, wireless+wired global roaming
Costs (provisioning)	Lower costs per byte Intermodal competition	Bursty traffic, Multimedia services, Fat-tailed usage profiles, Mergers & Acquisitions
Policy (spectrum reform)	Reduction of artificial scarcity	Technology neutrality Market-based licensing Unlicensed spectrum mgmt

Why hybrid sharing model makes sense…

Shared spectrum

-- lower cost access (too expensive to use "all dedicated," especially for bursty traffic)

-- some apps are delay tolerant (i.e., wait until spectrum available)

Dedicated spectrum

-- predictable interference environment → can guarantee QoS

-- some apps are not delay tolerant (need predictable access)

-- guaranteed QoS → premium service

Mix shared/dedicated → best of both worlds

-- guaranteed access for when it really has to get there…

-- match spectrum characteristics better to usage requirements

-- peak load provisioning problem (like power generation)

-- hedge your bets, low risk way to learn about sharing…

-- (more policy reform may be nice, but don't hold your breath….)

Business models for spectrum sharing

Spectrum must be shared much more intensively!

	Non-Cooperative	Cooperative
	Permission primary user not needed. No explicit coordination. Other users look like noise.	Permission primary user needed. Explicit coordination. Other signals recognizable.
Primary Sharing	Unlicensed, e.g., WiFi, Bluetooth	Secondary markets, e.g., leasing *Bandwidth Manager (real-time)* *Closed commons*
Secondary Sharing	Easements: -- underlay, e.g. UWB -- overlay, e.g., TV White space (LBT)	*Bilateral contracting*

*For more info, see Chapin & Lehr (2007a), Lehr (2009)

Where to start – a sample app for mixed spectrum model????

Bulk delivery to support high-capacity smartphones

Different types of communication: time sensitive vs insensitive

"Immediate" delivery service vs "bulk" delivery service

Bulk delivery may use exclusive, shared, or unlicensed spectrum

Based on cost, delivery time, congestion, etc.

Use bulk delivery for read-ahead and write-behind. Examples:

--Trickle down email attachments before user clicks on them

-- Pre-fetch web pages that user often checks

-- Distribute content such as video in the background

-- Media library synchronization

-- Periodic backups

-- etc….

Other applications for hybrid wireless broadband

Sensor networks

Daily routine reports: shared spectrum

Urgent updates: licensed spectrum ("earthquake detected!")

Communications in public venues e.g. stadiums

High-rent events: all in (temporarily) licensed spectrum

Low-rent events: small amount in licensed spectrum, most in shared

Ad-hoc networks

Control channel: licensed spectrum

- "who's there?"
- "where is the data channel today?"

Data links: small amount in licensed, surge capacity in shared

How to make hybrid systems affordable (1)

Exploit SDR infrastructure

Single network, single base station unit

Transmits multiple carriers

Some carriers always on in exclusively licensed spectrum

Some carriers intermittent in shared spectrum (based on etiquette)

- Different air interface standards are likely required

Expected initial business structure

One operator in a market deploys shared spectrum capability

Others lease access at wholesale rates

Policy recommendation

Promote spectrum sharing in bands close to licensed bands

Frequency agility for high-power base stations is expensive

How to make hybrid systems affordable (2)

Handset / CPE challenges

Need to match economics of existing radios that have global scale

Solution: add shared-spectrum capability to existing radio designs

Use adjacent, unpaired spectrum for sharing

- Avoid adding another antenna or amplifier

Re-use existing baseband chips

Re-use existing waveforms with small modifications

- Efficiency may be low at first
- Grow to more appropriate air interfaces for sharing as momentum builds

Policy recommendation

Target ~25MHz unpaired spectrum for sharing

Near existing mobile dedicated bands below 2.5GHz

How to make hybrid systems affordable (3)

Prioritize simplicity when choosing initial bands and access rules

Establish test-beds for real-world evaluations

DSA devices are hard to verify

Consider Time-Limited Leases (Chapin & Lehr, 2007)

Certification risk increases device cost, makes developers conservative

Support research on technical mechanisms to determine the source of intermittent interference

Assigning liability is hard when devices use dynamic spectrum sharing

Idea: "black box" that logs recent spectrum access decisions

Business models for spectrum sharing

Many models are possible

unlicensed, short-term leases, cooperative secondary access, noncooperative secondary access, co-primary access, **...**

Particularly of interest for hybrid wireless: closed commons

Multiple co-primary users

Restricted and managed access (all users agree to sharing protocol)

Predictable interference/availability

How to jumpstart experimentation with closed commons

Permit coalition bidding in auctions

- Challenging to avoid cartelization or static partitioning of license

Demonstrate success in public safety pooling

- (Lehr & Jesuale, 2008)

Summary

The future of wireless broadband is hybrid

Multiple technologies, multiple spectrum rights models

In particular, spectrum sharing will help provide core services

- Spectrum-sharing-only networks face significant economic challenges

Example applications

Bulk delivery of delay-tolerant price-sensitive data

Sensor networks, ad-hoc networks, public venues, **...**

Challenges and solutions to initiate mass-market adoption

Affordability: use SDR infrastructure, spectrum near mobile bands

Certification and liability: policies to promote simplicity

Business models: investigate closed commons

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Predicted spectrum needs by 2020

Spectrum requirements (MHz) for cellular voice and data
Allocations must be below 5 GHz

	2020	Europe, Middle East, and Africa		Americas		Asia-Pacific, Iran	
Demand model	Predicted Total	2006	Increase	2006	Increase	2006	Increase
Low	**1280**	**693**	**587**	**723**	**557**	**749**	**531**
High	**1720**	**693**	**1027**	**723**	**997**	**749**	**971**

Source: ITU-R Working Party 8F

Report M.2078 [IMT.ESTIMATE]

May, 2006

Analysis included
- Traffic projections and requirements
- Service and application requirements
- Spectrum efficiency
- Radio transmission characteristics
- Harmonized use of spectrum
- Technical solutions to facilitate global roaming
- Sharing and compatibility analysis