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Challenges of enabling high mobility in future flexible spectrum scenarios

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Introduction
Why do we need (high) mobility support …

- The expectation of being "always best connected"
  - Number of smart phones expected to double every three years [1]
    - 1.6 billon active smart phones by 2015 (25% of all active SIMs)
    - almost two smart phones / tablets shipped for every PC
  - Smart phone user less aware of underlying technology providing connectivity
    - Static usage → nomadic usage → true mobile usage of devices
    - bandwidth demands of smart phones / tablets higher than typical home PC
  - fear of operators having their networks being pushed to their capacity limits
    - offloading of traffic & users to most suitable, cost efficient network
    - focus business on „high value per bit traffic"
    - Revenue curve remains constant while traffic demand curve grows exponentially
- Intelligent offloading
  - Via smaller cells: femto cells, WLAN (lower cost, unlicensed spectrum)
  - Requires fast link set-up
    - for "walk-through off-loading opportunities"
    - For (highly) mobile users
- Making WiFi the best suitable, cost effective off-loading technology
  - What are the limits of standard compliant WiFi implementations in terms of supporting highly mobile users and how to achieve this limit?
  - What needs to be changed in 802.11?

[1] Generator Research Report: Worldwide Smartphone Markets: 2011 to 2015. United Kingdom, 2011.

Introduction
… and what about flexible spectrum access?

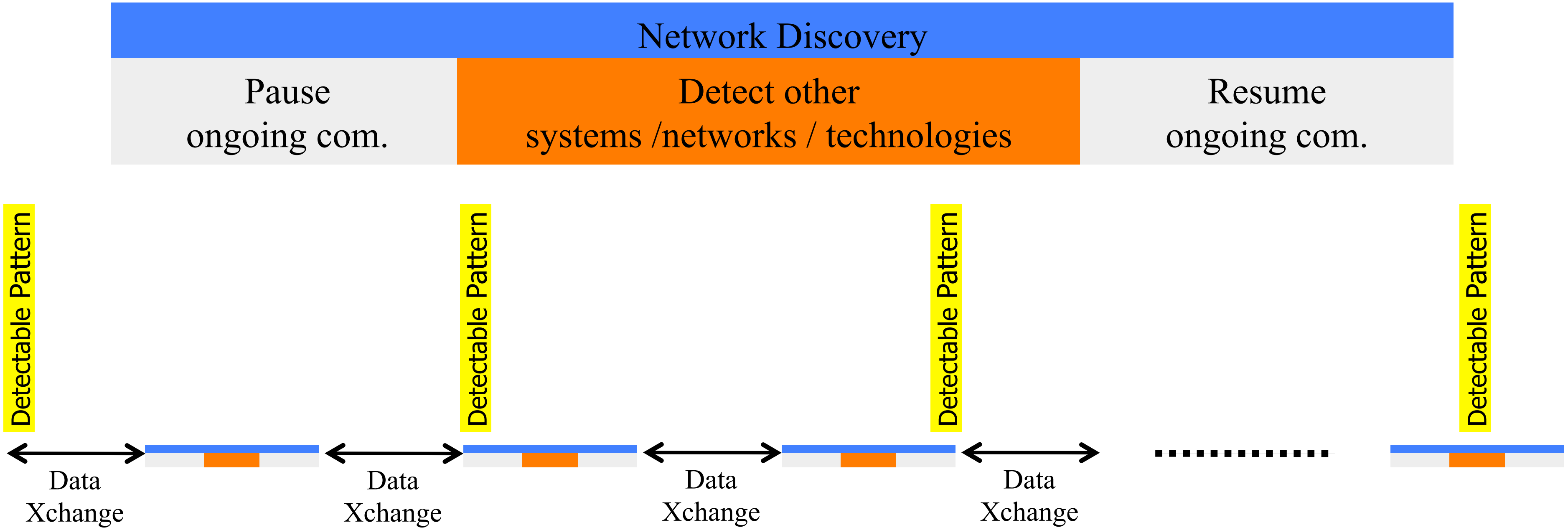
- The vicious circle of solving the problem
  - There is not a single / global best solution for fast link set-up support for offloading
    - We will face a portfolio of (algorithmic) approaches each associated with different cost and optimized for a specific degree of mobility support
    - Rule-based / cognitive decision schemes promising for selecting per user most suitable mobility support
  - Introducing lots of smaller cells for off-loading increases the power consumption
    - Even at times when they are not needed
    - Fixed frequency (range) has to be chosen for "peak traffic times" → range vs. data rate
  - Users are greedy, they expect more and more ☺
- How about flexible spectrum access?
  - Common trend towards OFDM-based PHY (regardless of technology)
    - Reuse or sharing of same hw-components
    - WLAN & Femto Cell APs available for shipment
  - Cognitive radio explores white spaces exploiting unused capacity
  - Further flexibility via software defined radios
    - Full flexibility in choosing technology and spectrum (from a portfolio of frequencies)
    - Sharing of recourses among operators
  - Dynamic spectrum access currently explored, mainly for nomadic users
- Is the limitation to nomadic usage is artificial, mandated by current regulation, or due to unresolved research issues accredited to adding (high) mobility to flexible, dynamic spectrum access scenario?

Agenda
What to expect in the next minutes

- **WiFi is (will be) suitable for mobility support & data offloading**
  - Finding APs while "on the move" – parallelization of AP discovery with data exchange
  - The problem of going towards smaller cells
  - Short term offloading: IEEE 802.11ai fast initial link set-up task group
    - AP Discovery enhancements
    - Network Discovery enhancements
    - Penalization of authentication & association with higher layer protocol exchange
- Dynamic Spectrum Access
  - Overview DSA Standardization
    - ETSI
    - IEEE 802.x
    - IEEE DySpan
  - New Vehicular activity in DySPAN
  - Spectrum Usage
    - from Regulatory Perspective
    - From a market perspective
  - Spectrum white spaces
  - Challenges of geolocation database approaches for mobile users
  - DSA for vehicular users – use cases
- Looking into a crystal ball – future DSA for mobile users

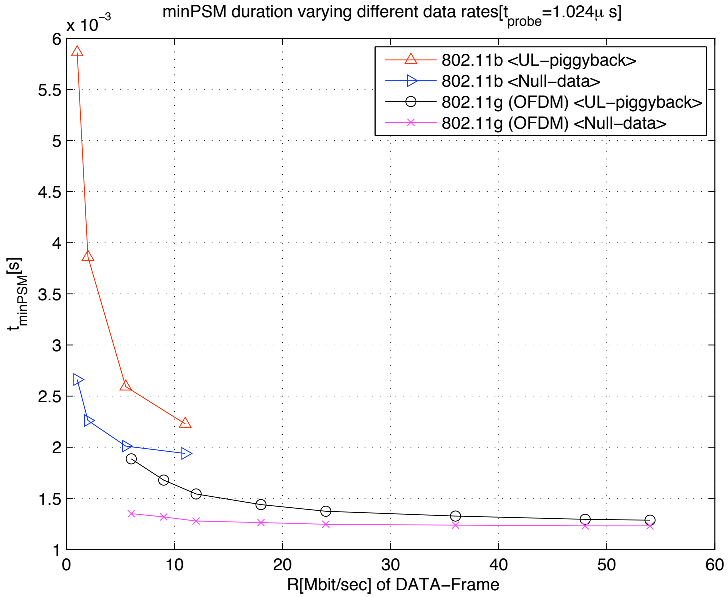
AP Discovery while Upholding connectivity
Opportunistic Scanning for 802.11

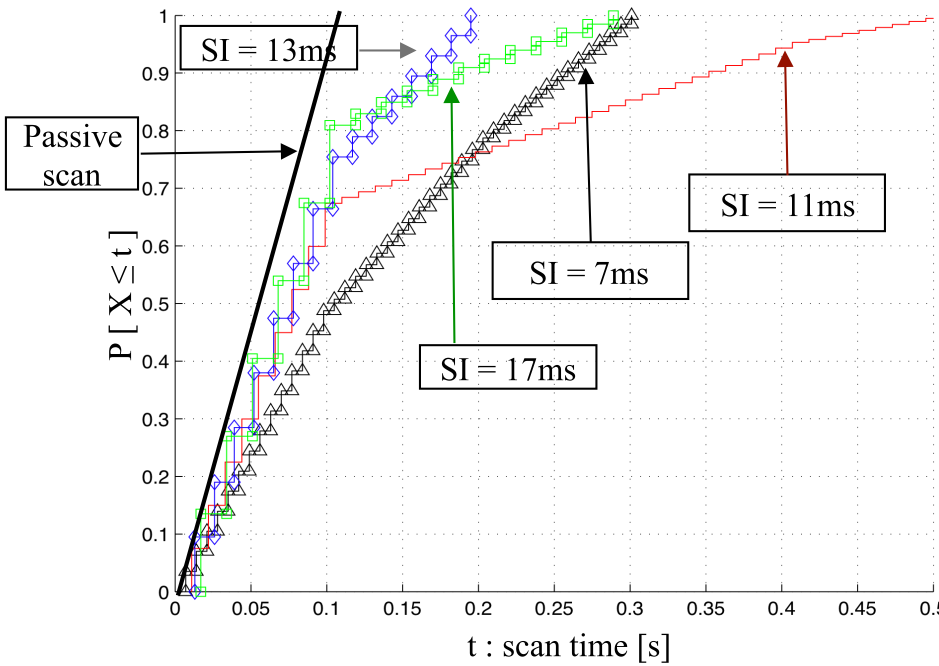
- Parallelize "search for new APs" while communication



- Can be done via 802.11 Power Save

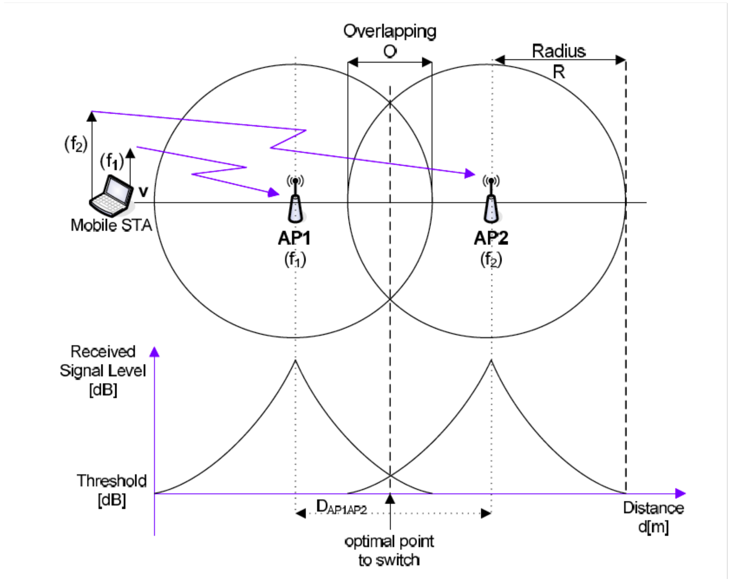
AP Discovery while Upholding connectivity
Performance of Opportunistic Scanning for 802.11





- Can be done maintaining backward compatibility with deployed devices
- Robust against increase in traffic load
  - Guarantee finding a beacon in less than 1s for “saturated links”
  - cost: approx 10% of bandwidth
- Requires some (node internal) changes of the management service primitives for scanning → ongoing: IEEE 802.11ai to add flexibility in MLME-scan service primitive

Seamless connectivity requires overlap
The Problem of going towards small cells

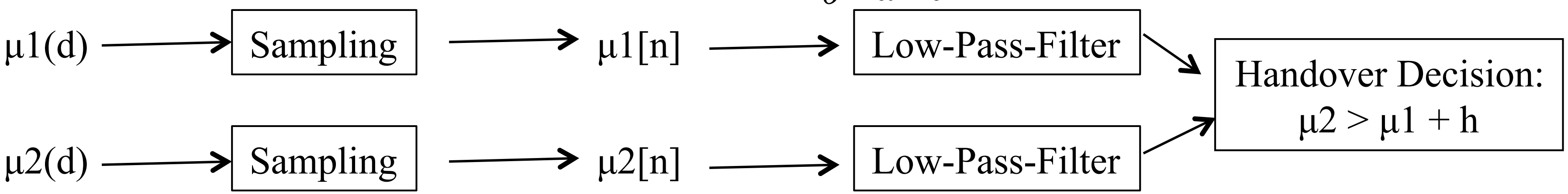


Two APs at distance D having an overlap O

Mobile STA traverses the coverage area of the APs and thereby receives a signal µ1 (d) and µ2 (d) from AP1 and AP2 respectively

Signal is low-pass filtered to reduce short term fading effects; handover is triggered if the signal of the target AP is by h larger (hysteresis margin)

$$\frac{1}{b}\int_{d-b}^{d}\mu_i(x)dx$$

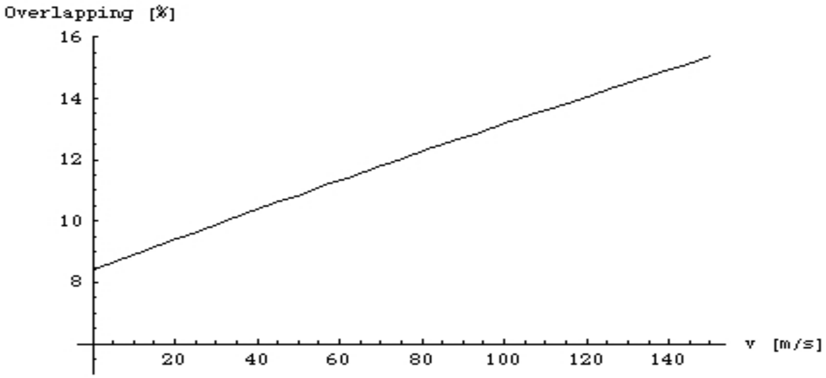


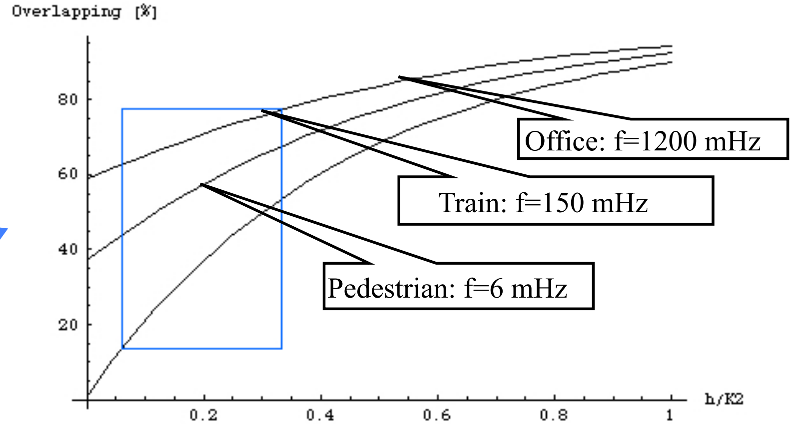
Handover decision has to occur while the mobile is within the overlap

Seamless Connectivity requires overlap

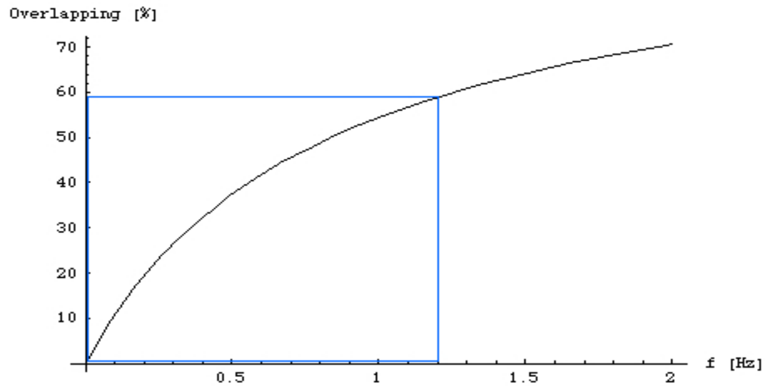
Adapt cell size / frequency dynamically to mobility needs

Overlap requirement for zero-delay handover direct proportional to mobile's velocity.





"Reformulate" observations to reveal effects of channel characteristics and handover frequency … it's just simple math ☺



- Using smaller cells / higher frequencies causes severe over provisioning in order to provide mobility support
- Means are required to dynamically choose best frequency at the user or to adapt selection of frequency sets at BSs feasible solution

Seamless Mobility Support is feasible staying within a technology

But is this really the dominant scenario to be considered?

IEEE 802.11 Fast Initial Link Set-Up
Focus of TGai

- TGai focuses on reducing the time spent in any phase of the initial link set-up

Phase	**AP Discovery**	**Network Discovery**	**TSF Sync. (1 additional scan)**	**Auth. & Assoc.**	**Higher Layer (DHCP / IP)**

- FIA has analyzed the performance of all link set-up phases (as imposed by IEEE 802.11-2007) and identified potentials for performance improvement
- The following summary of this analyzes illustrates some initial technical approaches on how to reduce the time spent in the initial link set-up phase

IEEE 802.11 Fast Initial Link Set-Up

AP Discovery for Initial Link Set-Up

Expected Mean of time spent in scanning for	No Assumptions (scan all channels), find all APs		No Assumptions (scan all channels), stop after 1st APs is found		Reduce number of channels (to 1) where APs are known to operate		Return after 1st AP Responses (scan 1 channel)		Enablement at 5GHz via 2.4 GHz	
	2.4 GHz	5 GHz	2.4 GHz	5 GHz	2.4 GHz	5 GHz	2.4 GHz	5 GHz	2.4 GHz	5 GHz
Passive scanning	1100 ms	2300 ms	550 ms	1150 ms	100 ms	100 ms	50ms	50ms	50ms	50ms
Active scanning	102 ms	n/a	22 ms	n/a	17 ms	n/a	2 ms	n/a	2 ms	2 + ε ms

Amendment required

11k may work, but **not** for initial link set-up
Amendment required

Combine both:
Amendment required

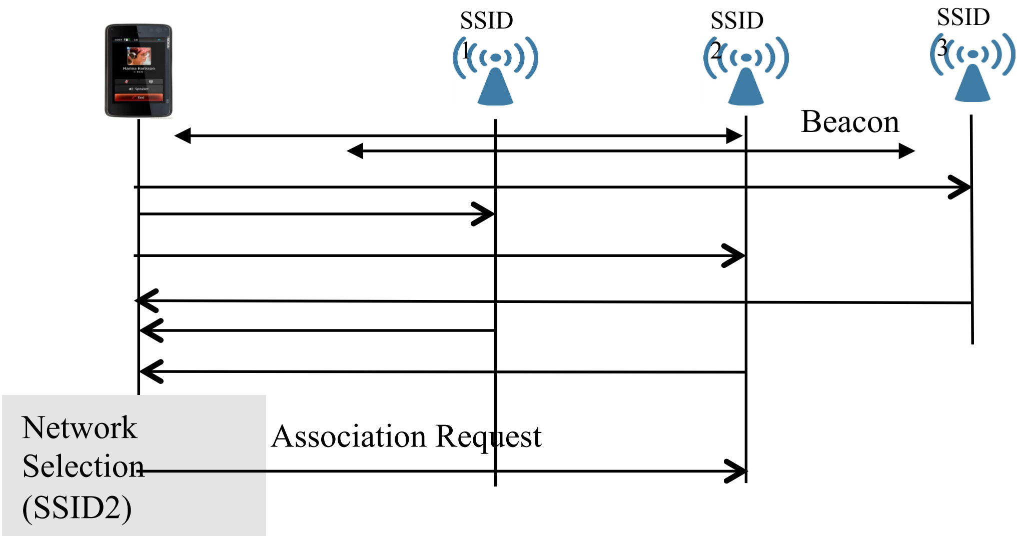
Amendment required

Increase in (externally available) knowledge

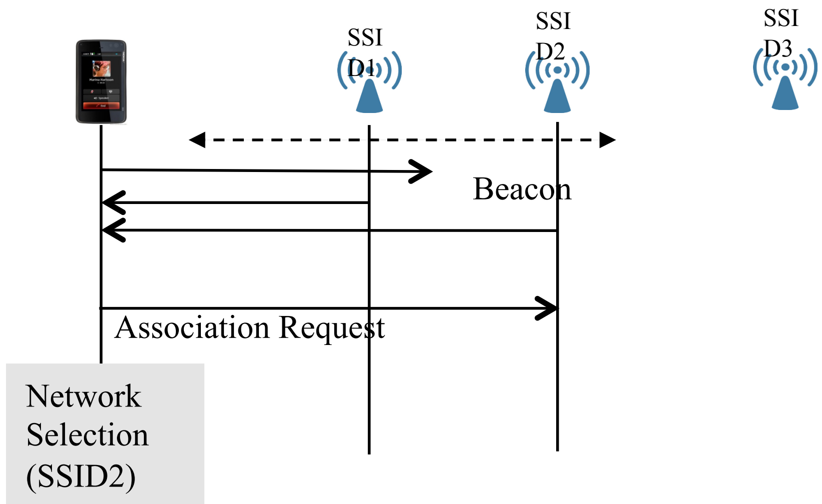
- Information on accessibility can be increasingly obtained from external sources in addition to the existing 802.11 schemes (e.g.: Offline WiFi Database for iPhone, location information in mobile devices, coverage maps, etc.)
- Such information can reduce the time spent in AP discovery, but as of today …
- 802.11 does not provide all means to fully exploit this potential
- Even without external information, scanning in 5GHz can be reduced from 2300ms down to 104ms (enablement via 2.4GHz; active scan of all channels at 2.4GHz, active scan of known channel w/ immediate return after 1st probe response on 5GHz channel)

IEEE 802.11 Fast Initial Link Set-Up
Network Discovery

- ANQP is unicast
- Each SSID is queried until a suitable network is found.



- ANQP to be sent to the broadcast address
- AP answers if it can satisfy the condition in the request
- ANQP responses are sent unicast



- Going from dedicated unicast-based approaches to multicast-based approaches
- Possibly combining AP & Network discovery into a single exchagne

IEEE 802.11 Fast Initial Link Set-Up
Association, Authentication & Higher Layer Protocols

- Start (parts of) the message exchange required for IP address assignment during the Auth. & Assoc. Phase

AP Discovery	**Network Discovery**	**TSF Sync. (1 additional scan)**	**Auth. & Assoc.**	**Higher Layer (DHCP / IP)**

AP Discovery	**Network Discovery**	**TSF Sync. (1 additional scan)**	**Auth. & Assoc.**
			Higher Layer (DHCP / IP)

- First evaluations: reduce time of this phase from 0.8 ms to 0.4 ms

Recap

- WiFi will very soon be capable of handling fast link set-up as required for offloading scenarios
- Supports several PHY (2.4, 5, 3.6, 60 GHz)
- Currently amended to work in TV White Spaces
- Clearly reflects the need for addressing horizontal market (11p exists for a while but has only achieved very limited market penetration)
- Even optimizing WiFi as it exists today requires
  - looking at advanced management schemes controlling the behavior of the technology depending on regulatory, service, and environmental requirements.
  - having a close look at the "spectrum to use" --- which is a challenge for nomadic users and regulation as it exists today; but visionary for mobile users and fully dynamic spectrum access
- The plurality of choices requires "advanced decision logic"
  - making reasonable decisions
  - considering the (current) purpose of a system

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Dynamic Spectrum Access
Definition

- Dynamic Spectrum Access (DSA) is

  The real-time adjustment of spectrum utilization in response to changing circumstances and objectives.
  NOTE—Changing circumstances and objectives include (and are not limited to) energy-conservation, changes of the radio's state (operational mode, battery life, location, etc.), interference-avoidance (either suffered or inflicted), changes in environmental/external constraints (spectrum, propagation, operational policies, etc.), spectrum-usage efficiency targets, quality of service (QoS), graceful degradation guidelines, and maximization of radio lifetime.

  (from IEEE Std 1900.1-2008)
- Is related to Dynamic Frequency Selection/Assignment/Sharing/Management.
- Bears all of regulatory/technological/business/coexistence issues.
- Demands for both technology-dependent and -independent approaches.
- Cognitive Radio is currently expected to provide a wide technological basis to address all of those issues.

Dynamic Spectrum Access Systems Standardization
ETSI RRS structure

- 36 registered participants
  - InterDigital, Huawei, NEC, NOKIA, FT/Orange, TI, ALU, ZTE, TeliaSonera, Telefonica, Telenor, Intel, Cable Europe, Sony, Fraunhofer …

- WG1 - System aspects
- WG2 - Reconfigurable Radio Equipment Architecture
- WG3 - Cognitive Management and Control
- WG4 - Public safety
- New work items
  - Feasibility study for coexistence between Cognitive Radio Systems operating in white spaces of the 470 – 790 MHz band and services delivered by existing RF Cable Networks operating in fixed wires in the same frequency
  - Spectrum Management in China

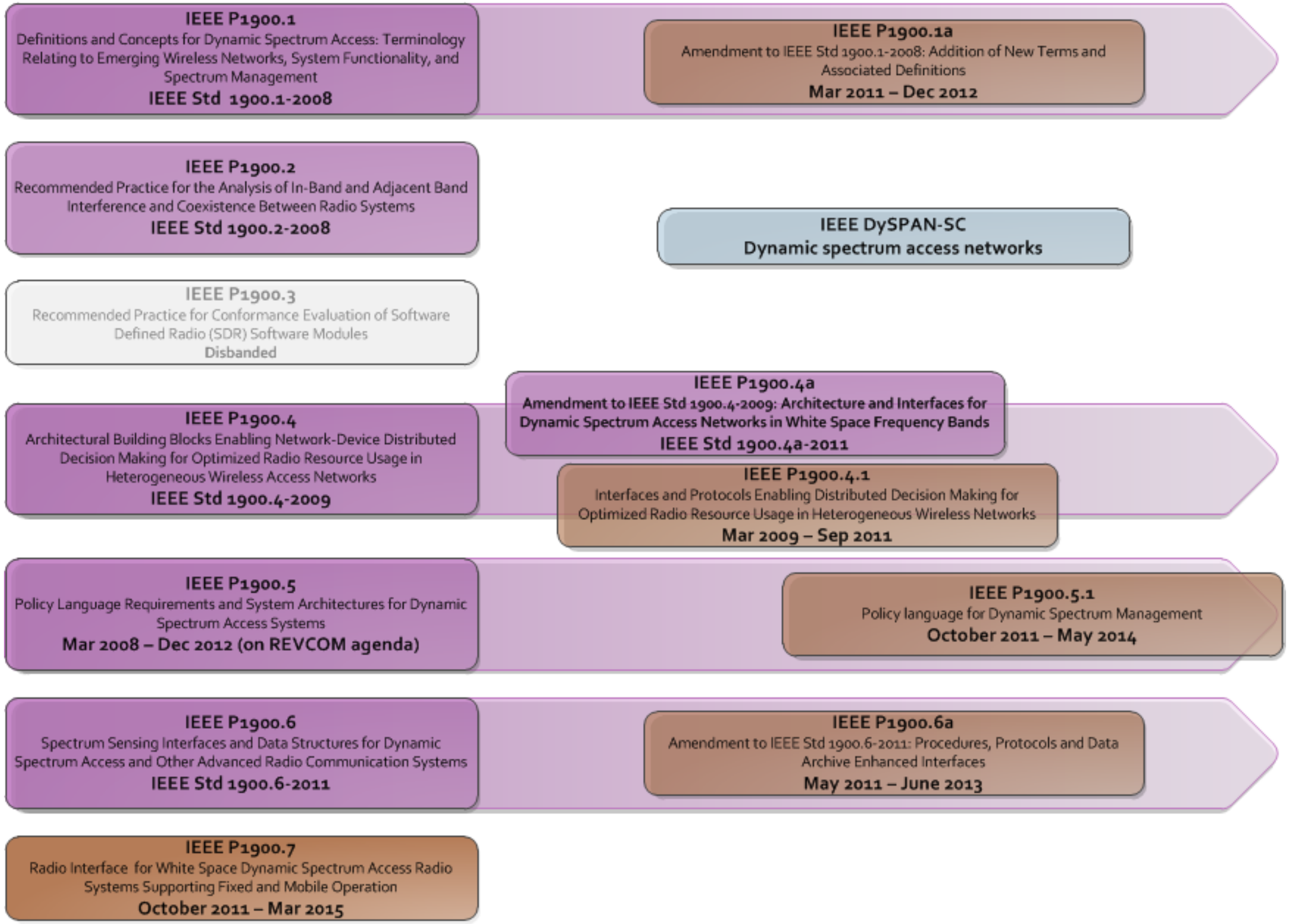
Dynamic Spectrum Access Systems Standardization
ETSI RRS current documents

TR 103 067	Feasibility study for Radio Frequency (RF) performances for Cognitive Radio Systems operating in UHF TV band WS
TS 102 946	System requirements for Operation in UHF TV Band White Spaces
TR 102 947	Use Cases for building and exploitation of Radio Environment Maps for intra-operator scenarios
TS 102 968	System requirements for Reconfigurable Radio Systems operating in IMT-Bands and GSM-Bands for intra-operator scenarios
TR 102 967	Use Cases for Dynamic Declaration of Conformity
TS 102 908	Coexistence Architecture for Cognitive Radio Networks on UHF White Space Frequency Bands
TS 102 969	Radio Reconfiguration related Requirements for Mobile Devices
TR 102 684	Feasibility Study on Control Channels for Cognitive Radio Systems
TR 102 970	Spectrum sharing and network sharing solutions for Public Safety communications based on RRS technology

Dynamic Spectrum Access Systems Standardization
Related topics in EEE 802.11

- IEEE 802.11 Wireless Next Generation Standing Committee
  - Topics related to mobility support for vehicular communications, dynamic spectrum access methods in the 2.4 GHz band, 802.11 for ultra wide band
- IEEE 802.11 TGaf
  - modifications to 802.11 PHY and MAC, to meet the legal requirements for channel access and coexistence in the TV White Space.
- IEEE 802.15.4 SG4TV
  - Physical layer for 802.15.4 meeting TV white space regulatory req.
- IEEE 802.18 Radio Regulatory Technical Advisory Group
  - Regulatory aspects of spectrum interference issues such as in the TV white space (TVWS) or by power line communications (PLC).
- IEEE 802.19 Wireless Coexistence Technical Advisory Group
  - Coexistence between IEEE 802 networks (e.g. mutual interference, discovery, MAC/PHY coexistence parameters, etc.).

Dynamic Spectrum Access Systems Standardization
IEEE DySPAN Standardization Committee

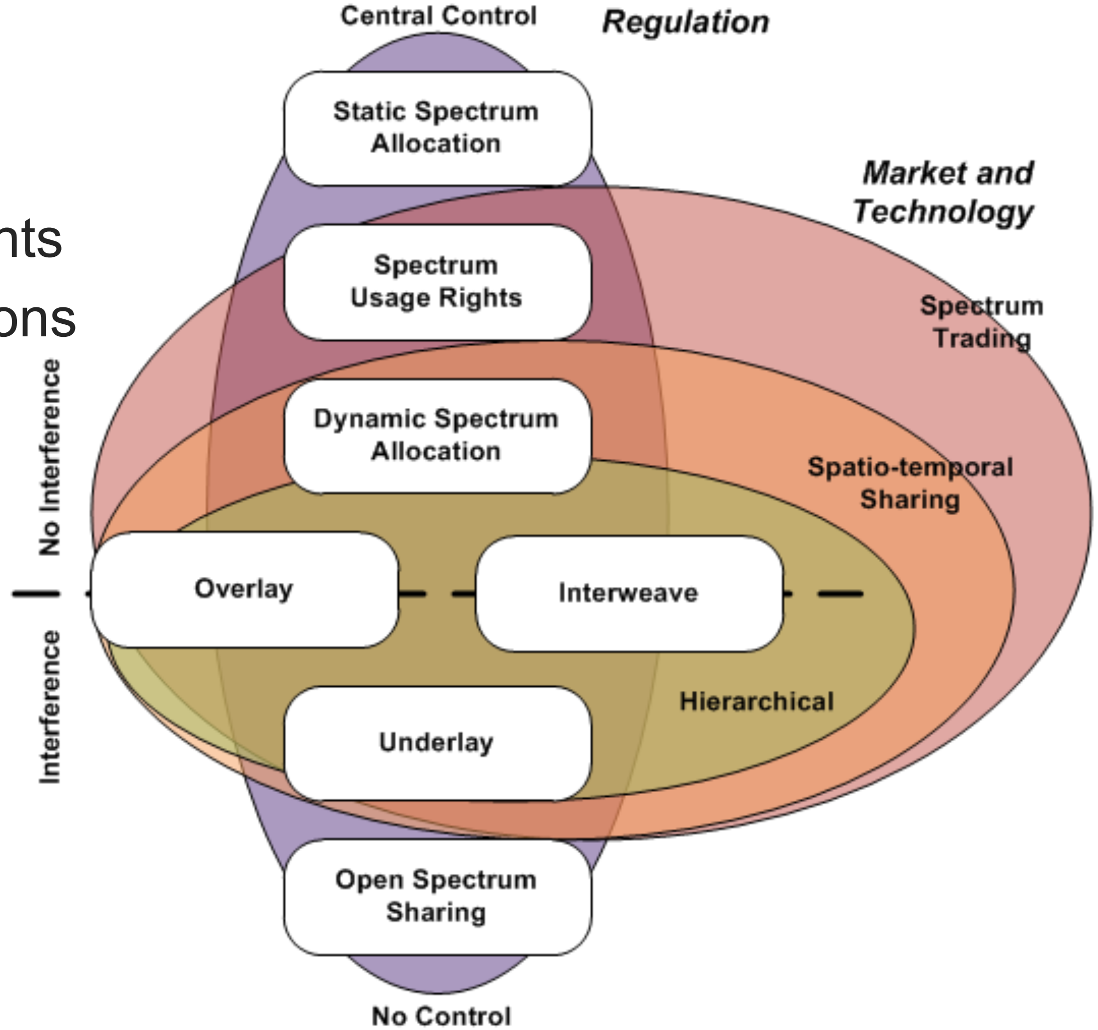


Dynamic Spectrum Access Systems Standardization
Dedicated IEEE DySPAN-SC Ad-hoc Group

- Dynamic Spectrum Access in Vehicular Environments (DSA-VE)
  - To identify the direction and the need to create a PAR on Dynamic Spectrum Access for Vehicular Communications. http://www.dyspan-sc.org/
- Potential focus topics
  - In-vehicle wireless communication (Human user as well as M2M, Machinery compartments, cabin, consist, …)
  - Vehicle-to-vehicle communication (Safety as well as non-safety ITS communication.)
  - Vehicle-to-wayside/roadside communication (DSRC as well as vehicle control)
  - Vehicle-to-infrastructure communication (Cellular for ITS as well as generic applications)
- Group will decide on next steps – decisions expected in December '11

Dynamic Spectrum Access
Spectrum usage from a regulatory perspective

- All spectrum is regulated
  - Spectrum allotment to technologies or incumbents
  - Dedicated shared commons for licensed technologies
- Any spectrum user needs to be licensed – License determines usage rights of spectrum for a certain
  - Frequency,
  - Location,
  - Duration,
  - Technology,



Dynamic Spectrum Access
Spectrum usage from a market perspective

- Future spectrum management practice is expected to be
  - Market based (beyond the auction-based / beauty-contest model),
  - Technology-neutral (usage rules rather than technology license),
  - Open for spectrum sharing (while protecting incumbents).
- A license may determine technology independent temporary spectrum usage rights for a certain frequency, location, and duration.
- New spectrum sharing models expected. For example
  - Spectrum pooling
  - Spectrum (micro-) trading
  - Opportunistic spectrum access
  - Shared commons

Dynamic Spectrum Access
Spectrum white space

- White space: (spatio-temporal) underutilized spectrum that can be used by opportunistic users given that no harm to incumbents is caused.
- Current white space regulations (for TV and radar bands) is implementing a spectrum usage rights model through a geolocation database allowing spectrum users to obtain a (temporary) lease.
- Potential issues foreseen with the database model:
  - Incumbent protection (how to mitigate harm to incumbents?)
  - Scalability (how to support billions of M2M users?)
  - Mobility support (how to support frequent position updates?)
  - Non-repudiation (how to spot interferers?)
- Enabling of white space spectrum users relies on continuous and trusted access to a geolocation database.

Dynamic Spectrum Access
Geolocation database approach – incumbent protection issues

- Challenge: how to mitigate harm to incumbents?
  - Policies are issued by the regulator – database needs to follow.
  - Interference estimation is based on path loss and terrain models.
  - Accuracy of interference estimation is crucial both for economical and incumbent protection reasons.
  - Depending on variance of the path loss model, spectrum user's allowed transmit power may vary by several 10s of dB.
- Current solution: models incorporated in the database consider a significant safety margin in terms of RF signal strength and spatial distance (see e.g. ECC Report 159).
- Upcoming topics
  - The database needs to consider accumulated interference by multiple spectrum users.
  - Spectrum sensors may assist in verification/optimization of models.
  - Mobile sensors may contribute to building a "global RF environment map".

Dynamic Spectrum Access
Geolocation database approach – scalability issues

- Challenge: how to support billions of M2M users?
  - Database provides operating parameters for spectrum users from knowledge about position and vulnerability of incumbents.
  - Needs to scale with number of incumbents and spectrum users.
  - Must record lease parameters to compute accumulated interference level.
  - Serves dedicated geographical areas or dedicated set of users and needs collaboration with other databases.
  - May consider multiple regulatory domains (e.g. across national borders).
- Current solution: None. Unclear if database model can scale and satisfy regulatory demands (i.e. incumbent protection) at the same time.
- Upcoming topics
  - large scale device command and control (e.g. IEEE 802.15.4 (SG4TV).
  - Smart Grid and Infrastructure Monitoring and "White Space Regional Area Grid" (e.g. IEEE 802.22)
  - Vehicular networks / ad-hoc networks of mobile users to be new SmartGrid++

Dynamic Spectrum Access
Geolocation database approach – mobility issues

- Challenge: how to support frequent position updates?
  - Current approaches require the spectrum user to register with its current position and to obtain a license with limited lease time (minutes to hours).
  - Portable or mobile users need to register or update frequently (minutes to seconds).
- Current solution: limit spectrum use to portable devices and low mobility
- Upcoming topics
  - Cellular systems may need to register for larger areas (as a proxy for their mobile users).
  - Mobile (e.g. in-vehicle) networks may require a co-located (approved/ certified) mobile geolocation database.
  - Databases may need to consider mobility models.
  - Practical solutions need to avoid “new” underutilization of spectrum.

Dynamic Spectrum Access
Geolocation database approach – non-repudiation issues

- Challenge: how to spot interferers?
  - A spectrum user may produce interference due to malicious use, defective devices or unexpected environmental conditions.
  - A spectrum user may respect its contract but may not be aware of causing interference.
  - Interferers must be located and license must be withdrawn.
- Current solution: disable all spectrum users in the affected area
- Upcoming topics
  - Interferers disposing of a valid spectrum lease may raise liability issues.
  - Detecting interferers may require neighbouring spectrum users to act as spectrum sensors.
  - Difficult to locate mobile interferers
    - May require collaboration among neighbouring spectrum users
    - May need support by mobile sensors

Dynamic Spectrum Access
Use cases for DSA in vehicular environments

- DSA in vehicular environments may be needed to enable
  - Interoperation with upcoming wireless infrastructures based on flexible spectrum use and sophisticated spectrum management.
  - Offloading for limited capacity ITS frequency bands.
  - Data traffic congestion mitigation in high density emergency situations.
  - Coexistence in wireless network mobility
  - M2M or device command and control for interference prone wireless in-vehicle communication
- Vehicular communication may benefit from DSA by
  - Countering temporal wireless link degradation by dynamic frequency selection, optimizing propagation conditions.
  - Increasing robustness and dependability in the presence of malicious spectrum users (e.g. RF jamming).

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Crystal Ball

Future DSA for mobile users

- Spectrum is a scarce natural resource
  - As long as spectrum is 'more expensive than technology' flexible spectrum use is a key enabler for handling the ever increasing bandwidth demand of wireless communications
- Regulators are keen to get confidence in DSA
  - Regulations often is less nippy than technology: it may even slow down market introduction of promising new technologies; but regulators need confidence in the maturity of a technology since they are obliged to care.
- DSA in high mobility scenarios is a new area
  - Key technologies such as spectrum sensing, real-time decision-making and reconfigurable radio are pushed to the limits, but benefits would be tremendous.
- Research required to make future DSA for (highly) mobile users happen
- Market relevance via a suitable migration path required. Avoid clean slate approaches until dynamic DSA is accredited. Build upon accepted, commercially relevant technologies.

Where to go from here
References and More Face-to-face Discussion

- Slides available online at http://www.emmelmann.org
  (please grant me 10 day to return to the office and take care of the upload ☺)

- Upcoming Tutorial „Dynamic spectrum access, cognitive radio networks, and spectrum management as key enablers for upcoming mobile communications – Understanding opportunities and coexistence requirements from evolving developments in research, standardization, regulations and technology." at the upcoming Fuseco Forum

Enter the rebate promo code `LCN_15` at the registration form at

www.fuseco-forum.org/registration