Cognitive Radio Capability Matrix

Definer	Adapts (Intelligently)	Autonomous	Can sense Environment	Transmitter	Receiver	"Aware" Environment	Goal Driven	Learn the Environment	"Aware" Capabilities	Negotiate Waveforms	No interference
FCC	•	•	•	•							
Haykin	•	•	•	•	•	•	•	•			
IEEE 1900.1	•	•	•	•	•						
IEEE USA	•	•	•	•	•	•					•
ITU-R	•	•	•	•	•	•					
Mitola	•	•	•	•	•	•	•	•	•	•	
NTIA	•	•	•	•	•	•	•				
SDRF CRWG	•	•	•	•	•		•				
SDRF SIG	•	•	•	•	•	•	•	•	•		
VT CRWG	•	•	•	•	•	•	•	•	•		

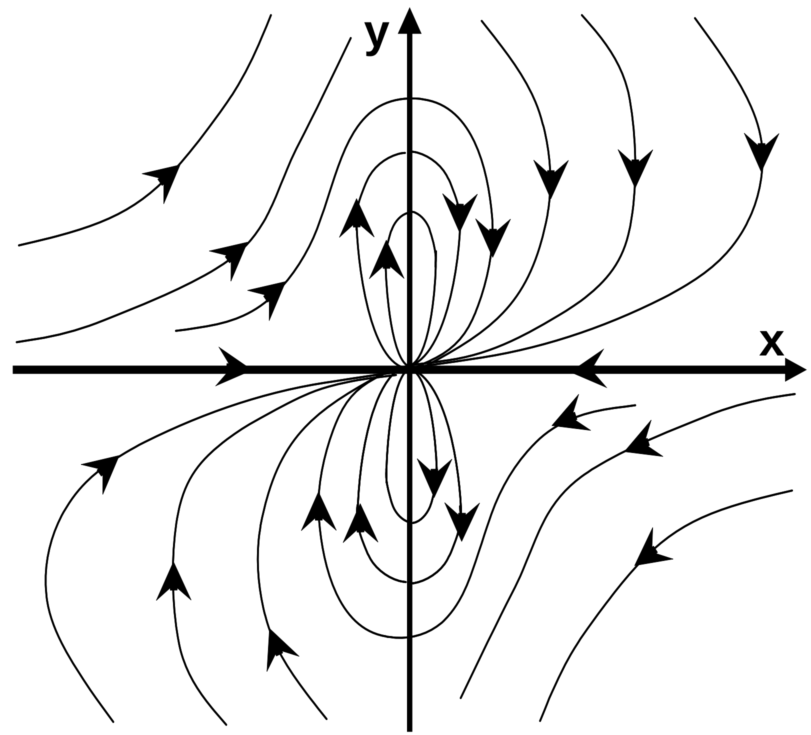
Modeling Cognitive Radios as a Dynamical System

- *<u>Dynamical system</u>*
  - A system whose change in state is a function of the current state and time
- Autonomous system
  - Not a function of time
  - OK for synchronous timing
- Characteristic function

$$\dot{a} = g\left(a, t\right)$$

- Evolution function $d : A \times T \to A$
  - First step in analysis of dynamical system
  - Describes state as function of time & initial state.
  - For simplicity $d = \times_{j \in N} d_j = d : A \to A$

while noting the relevant timing model



Optimality

- In general we assume the existence of some design objective function J:A$\rightarrow\mathbb{R}$
- The desirableness of a network state, *a*, is the value of *J*(a).
- In general maximizers of *J* are unrelated to fixed points of *d*.

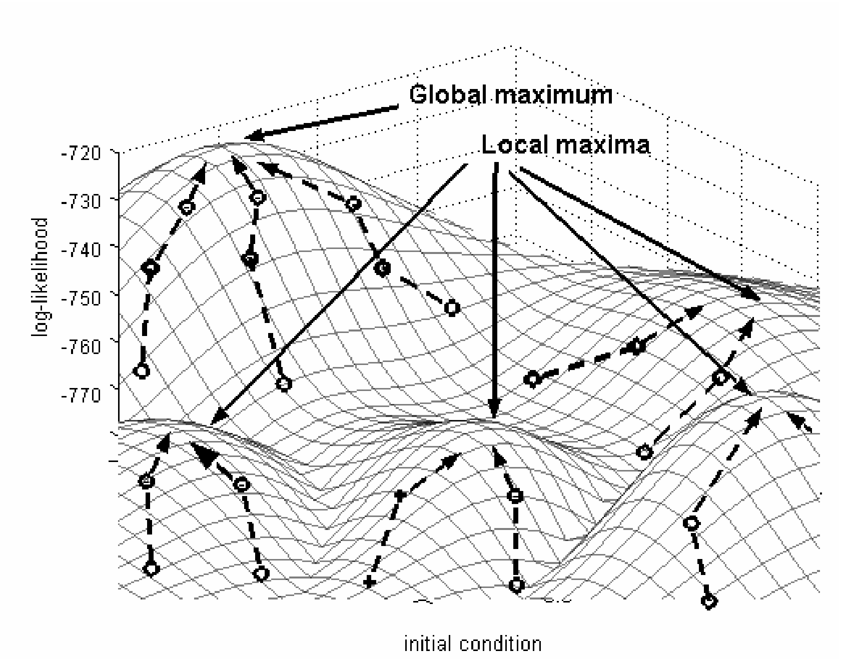
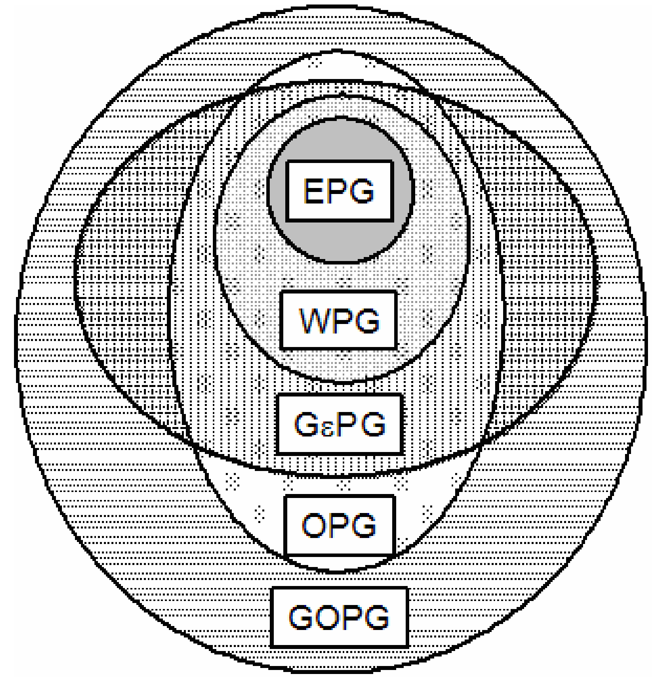
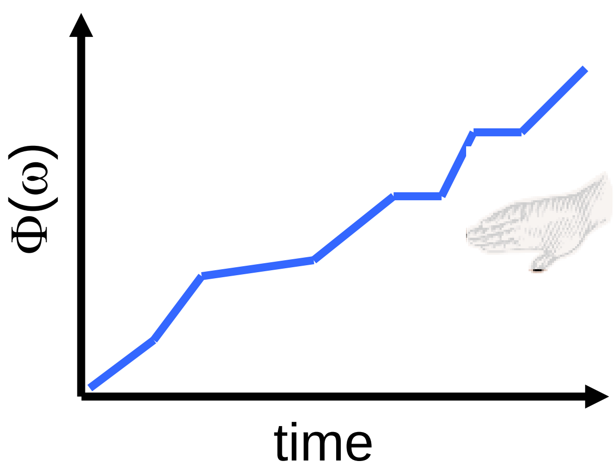


Figure from Fig 2.6 in I. Akbar, “Statistical Analysis of Wireless Systems Using Markov Models,” PhD Dissertation, Virginia Tech, January 2007

Potential Games

- Existence of a function (called the potential function, *V*), that reflects the change in utility seen by a unilaterally deviating player.
- Cognitive radio interpretation:
  - Every time a cognitive radio unilaterally adapts in a way that furthers its own goal, some real-valued function increases.

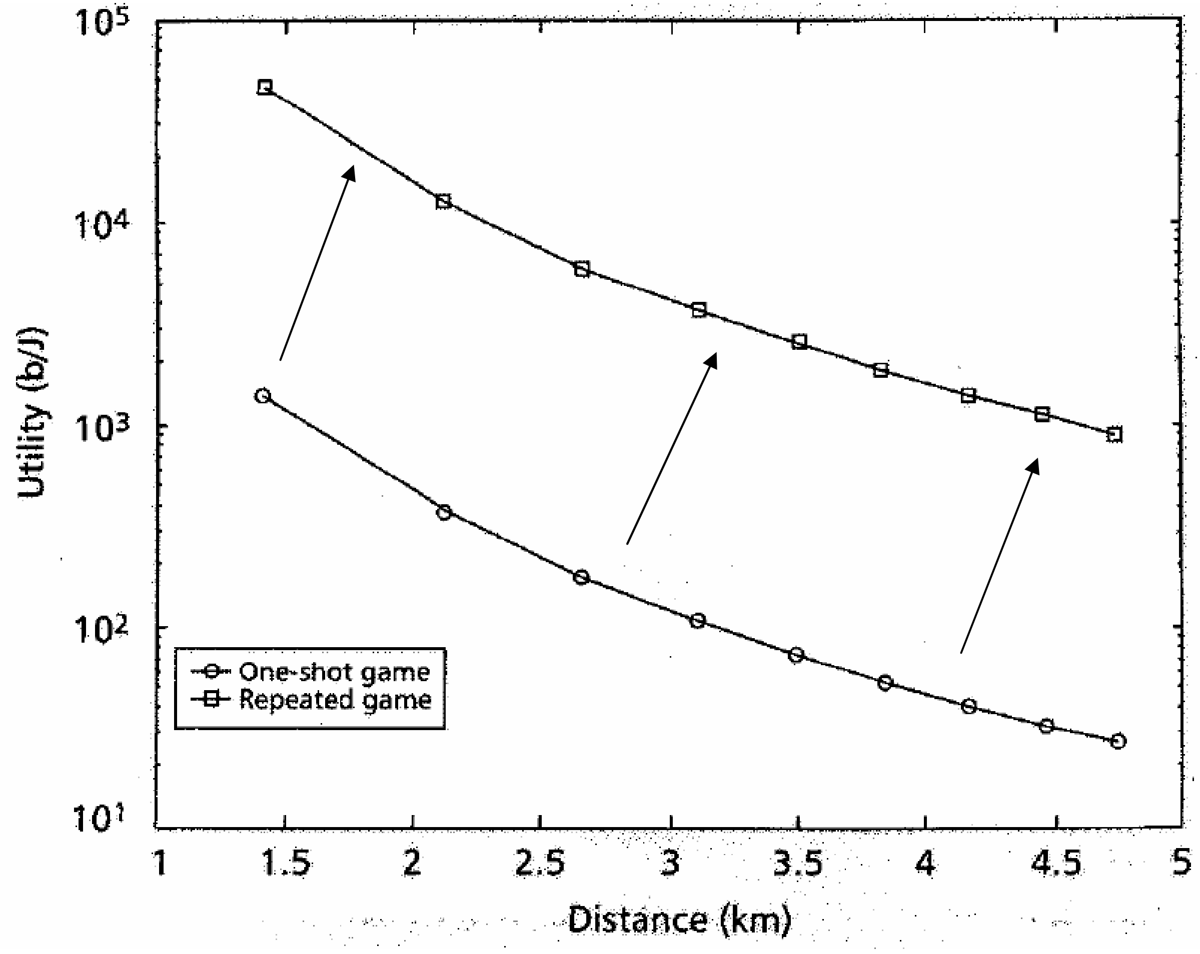




Potential Game	Relationship $(\forall i \in N, \forall a \in A)$
Exact (EPG)	$u_i(b_i,a_{-i}) - u_i(a_i,a_{-i}) = V(b_i,a_{-i}) - V(a_i,a_{-i})$
Weighted (WPG)	$u_i(b_i,a_{-i}) - u_i(a_i,a_{-i}) = \alpha_i\left[V(b_i,a_{-i}) - V(a_i,a_{-i})\right]$
Ordinal (OPG)	$u_i(b_i,a_{-i}) - u_i(a_i,a_{-i}) > 0 \Leftrightarrow V(b_i,a_{-i}) - V(a_i,a_{-i}) > 0$
Generalized Ordinal (GOPG)	$u_i(b_i,a_{-i}) - u_i(a_i,a_{-i}) > 0 \Rightarrow V(b_i,a_{-i}) - V(a_i,a_{-i}) > 0$
Generalized ε (GεPG)	$u_i(b_i,a_{-i}) > u_i(a_i,a_{-i}) + \varepsilon_1 \Rightarrow V(b_i,a_{-i}) > V(a_i,a_{-i}) + \varepsilon_2$

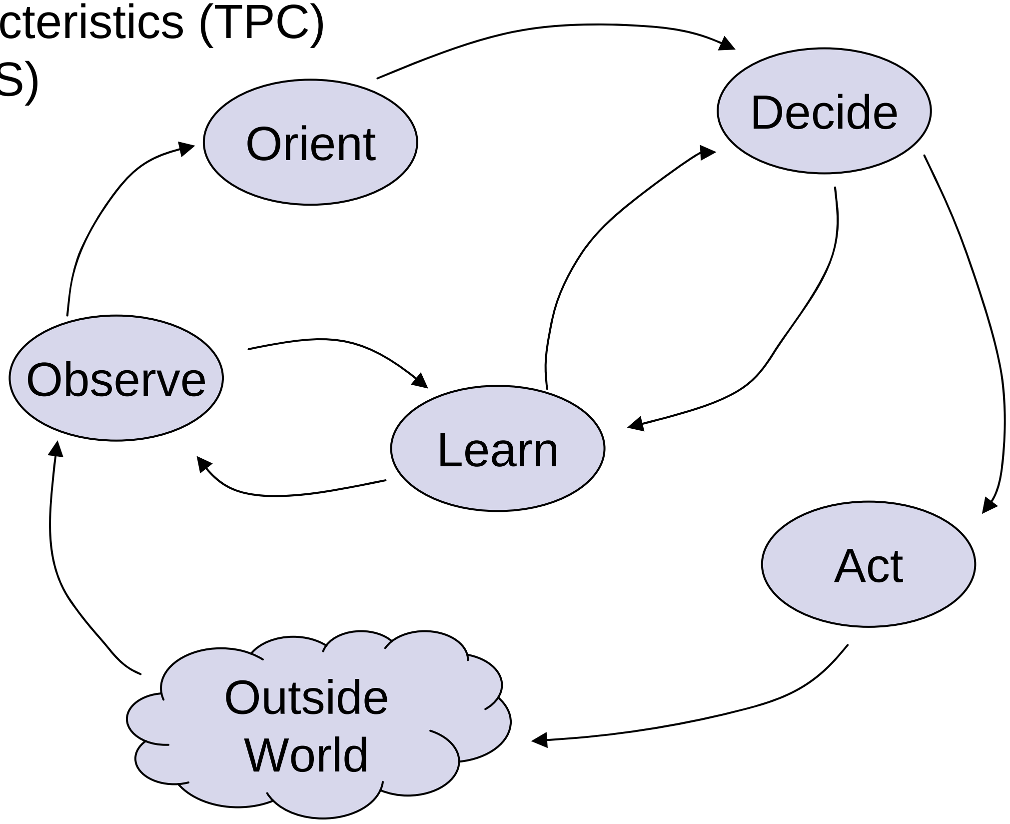
Improvement from Punishment

- Throughput/unit power gains be enforcing a common received power level at a base station
- Punishment by jamming
- Without benefit to deviating, players can operate at lower power level and achieve same throughput



A. MacKenzie and S. Wicker, "Game Theory in Communications: Motivation, Explanation, and Application to Power Control," *Globecom2001*, pp. 821-825.

802.11h: A simple cognitive radio



Observe

- Must estimate channel characteristics (TPC)
- Must measure spectrum (DFS)

Orientation

a) Radar present?
b) In band with satellite??
c) Bad channel?
d) Other WLANs?

Decision

- Change frequency
- Change power
- Nothing

Action

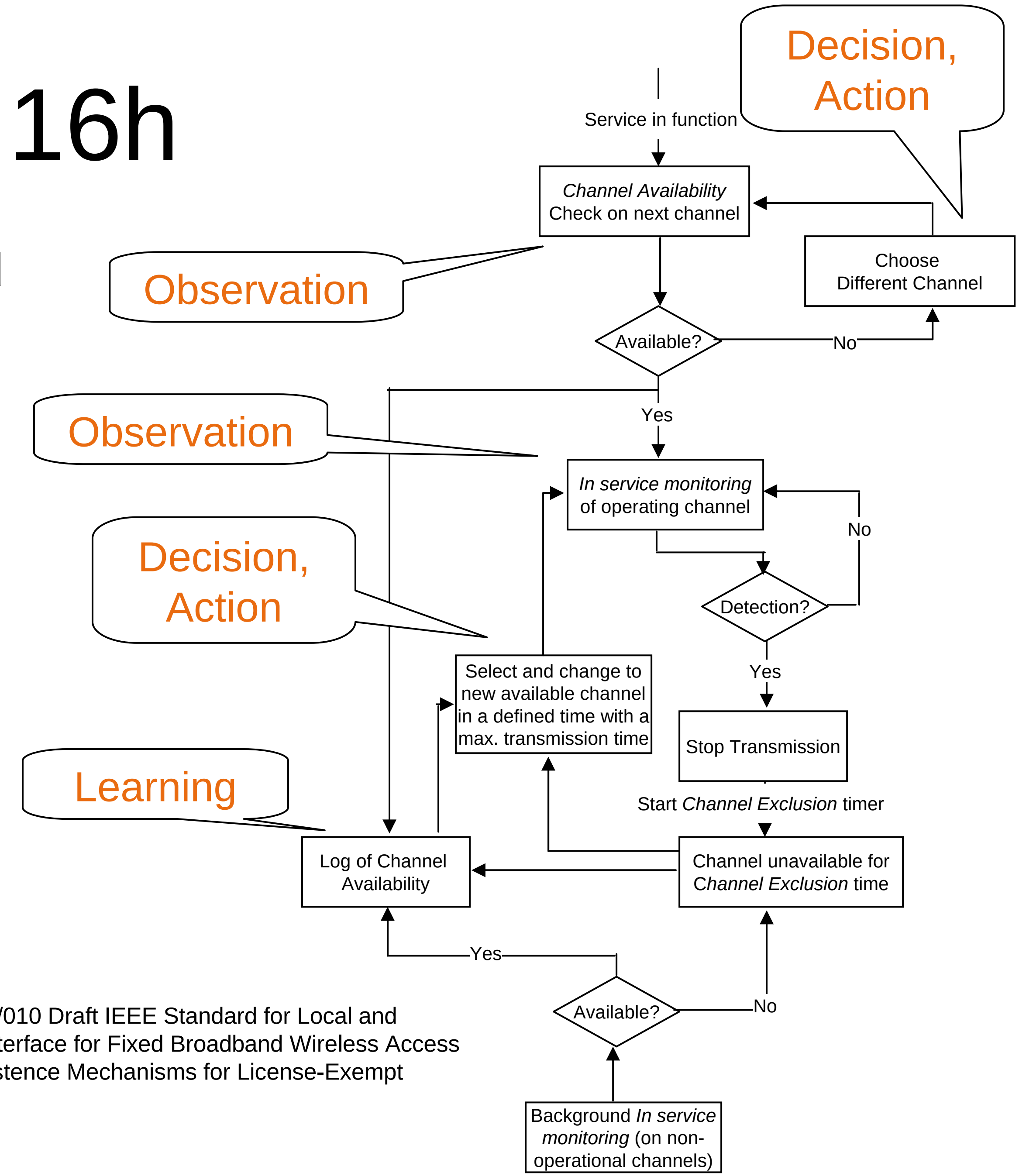
Implement decision

Learn

- Not in standard, but most implementations should learn the environment to address intermittent signals

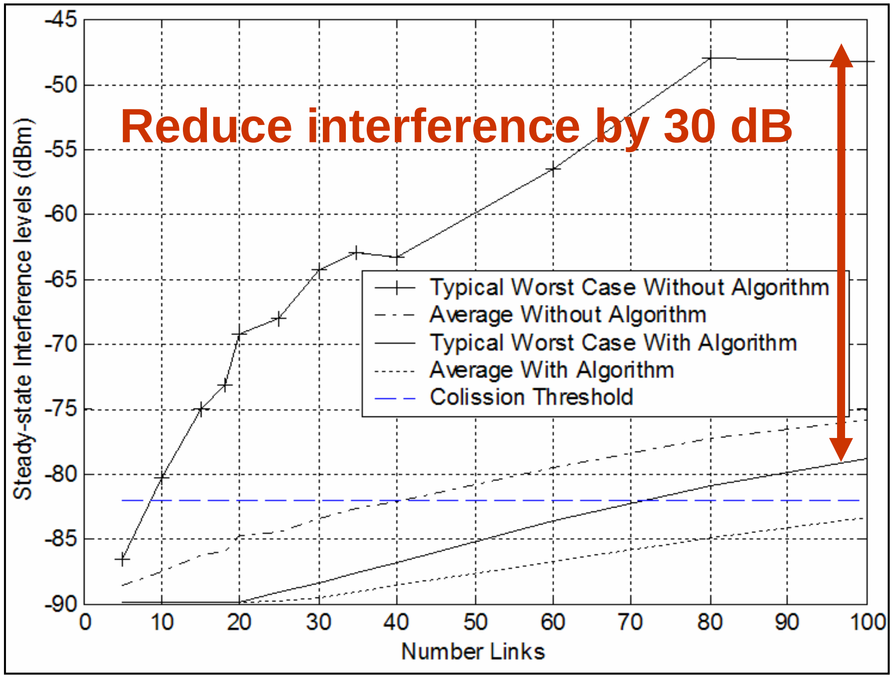
DFS in 802.16h

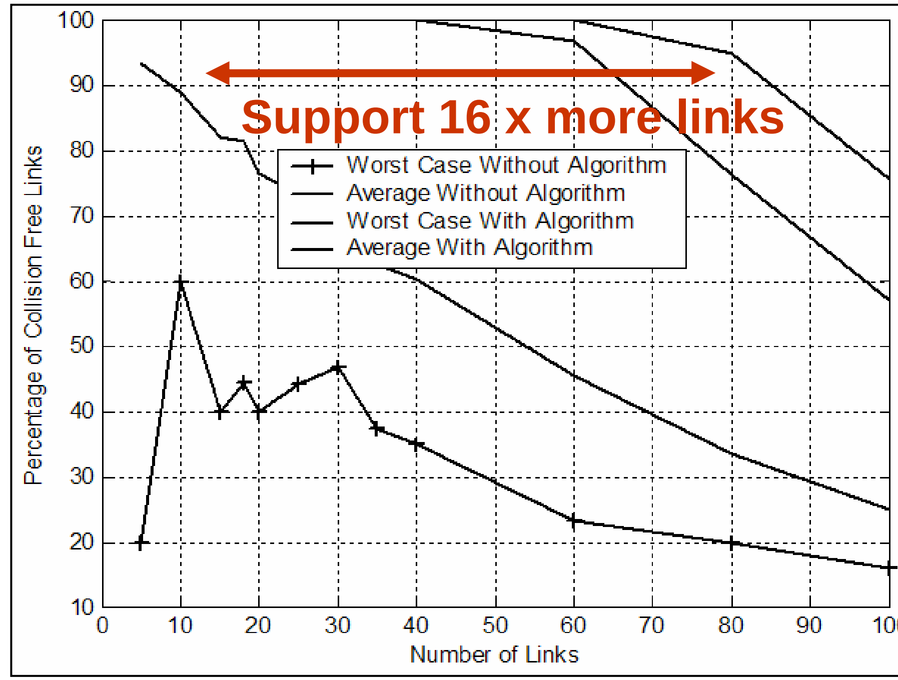
- Drafts of 802.16h defined a generic Dynamic Frequency Selection algorithm which implements observation, decision, action, and learning processes
- Very simple implementation



Modified from Figure h1 IEEE 802.16h-06/010 Draft IEEE Standard for Local and metropolitan area networks Part 16: Air Interface for Fixed Broadband Wireless Access Systems Amendment for Improved Coexistence Mechanisms for License-Exempt Operation, 2006-03-29

Aggregate Statistics for Peer-to-Peer Network





- Similar algorithm but cognitive decision processes span links
- No coordination between decision processes
- Localized reasoning leads to global optima
- Steady-state performance equivalent to centralized local search