Game Theoretical Approaches for Spectrum Sharing in Wireless Communication

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1. Wireless Communication
2. License Exempt Frequency Bands
3. ETSI BRAN HiperLAN/2 and IEEE 802.11a
4. Coexistence and Resource Sharing
5. Brief Discussion on Game Theory
6. Conclusion

Motivation

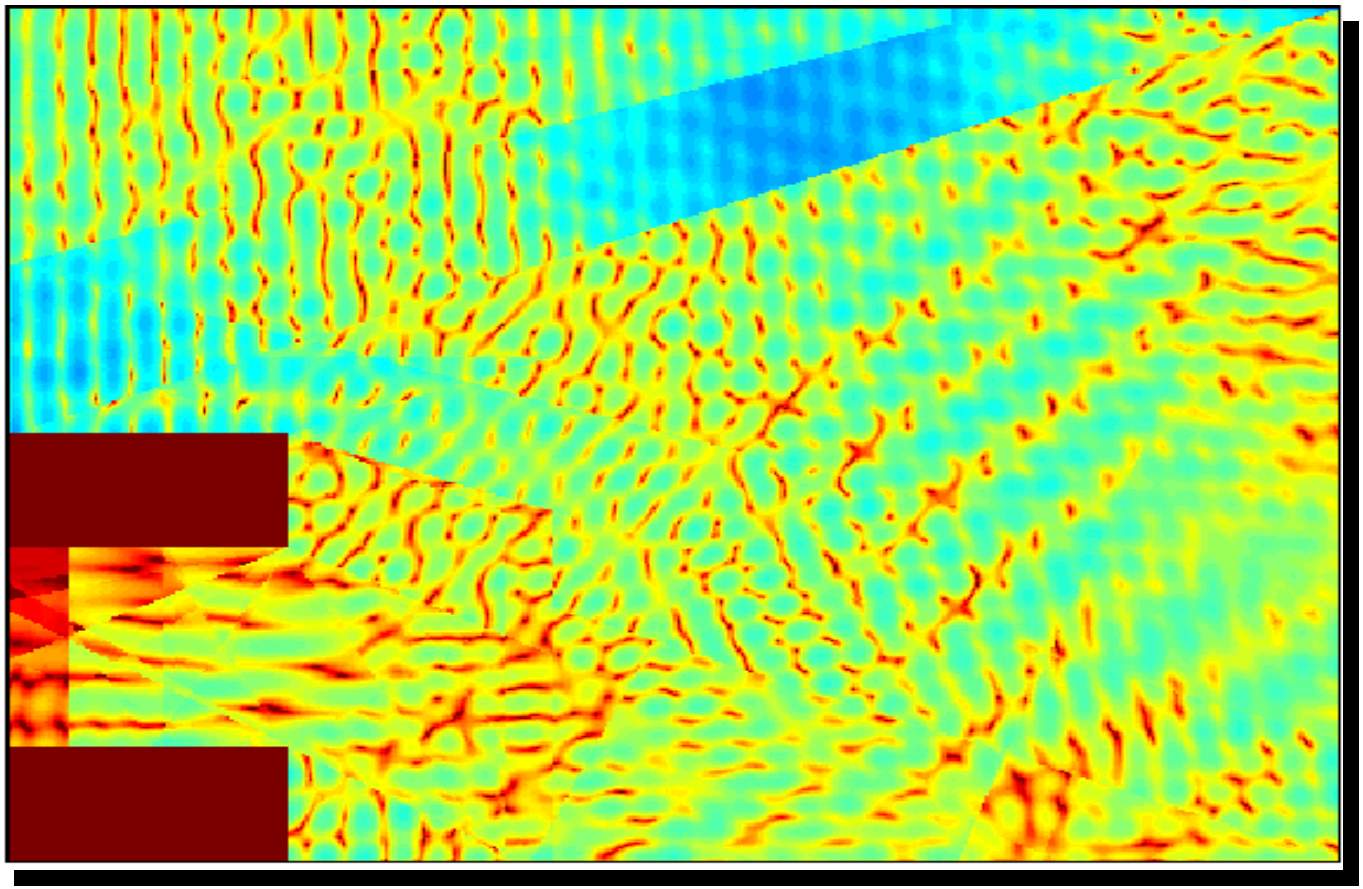
1. Wireless Communication is a key technology for the Information Society
2. The Next-Generation Internet will provide services and information at a high rate and with high reliability
3. Governments, regulators, manufacturers, and network operators keep pacing for better services, at any time, anywhere, including mobility
4. According to UN's ITU, developing countries may be able to finally close the gap with the help of wireless communication
5. Frequency spectrum is the bottleneck here, needs careful allocation
6. There´s a relative new problem in telecommunication, which requires in-depth understanding of competition and coordination strategies:

Coexistence of competitive wireless communication networks, operating at the same frequencies

Wireless Communication

1. Difficult media
    - interference and noise
    - quality varies over space and time
    - shared with “unwanted” devices (in un-licensed spectrum, microwave ovens)
2. Full connectivity cannot be assumed
    - “hidden node” problem
3. Multiple international regulatory requirements
4. Mobility
    - variation in link reliability
    - battery usage: requires power management
5. Security
    - no physical boundaries

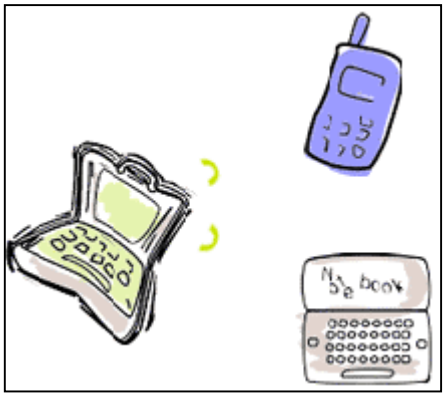
Medium Variations in Wireless Communication

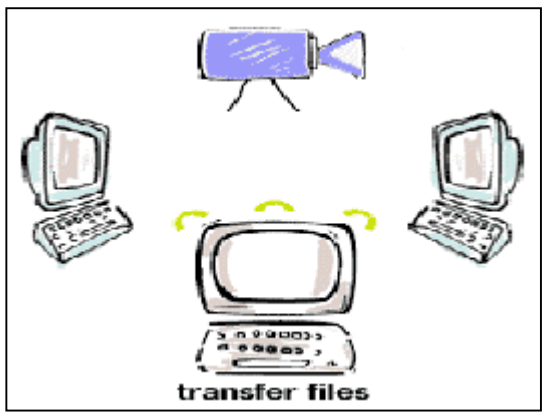


(C) IEEE

Spectrum Efficiency and Service Reliability

1. Throughput and quality of wireless voice and data depends on the allocated bandwidth
2. National Regulatory Bodies decide what system is allowed to operate at what frequency
3. The spectrum is the key resource to be carefully and efficiently used

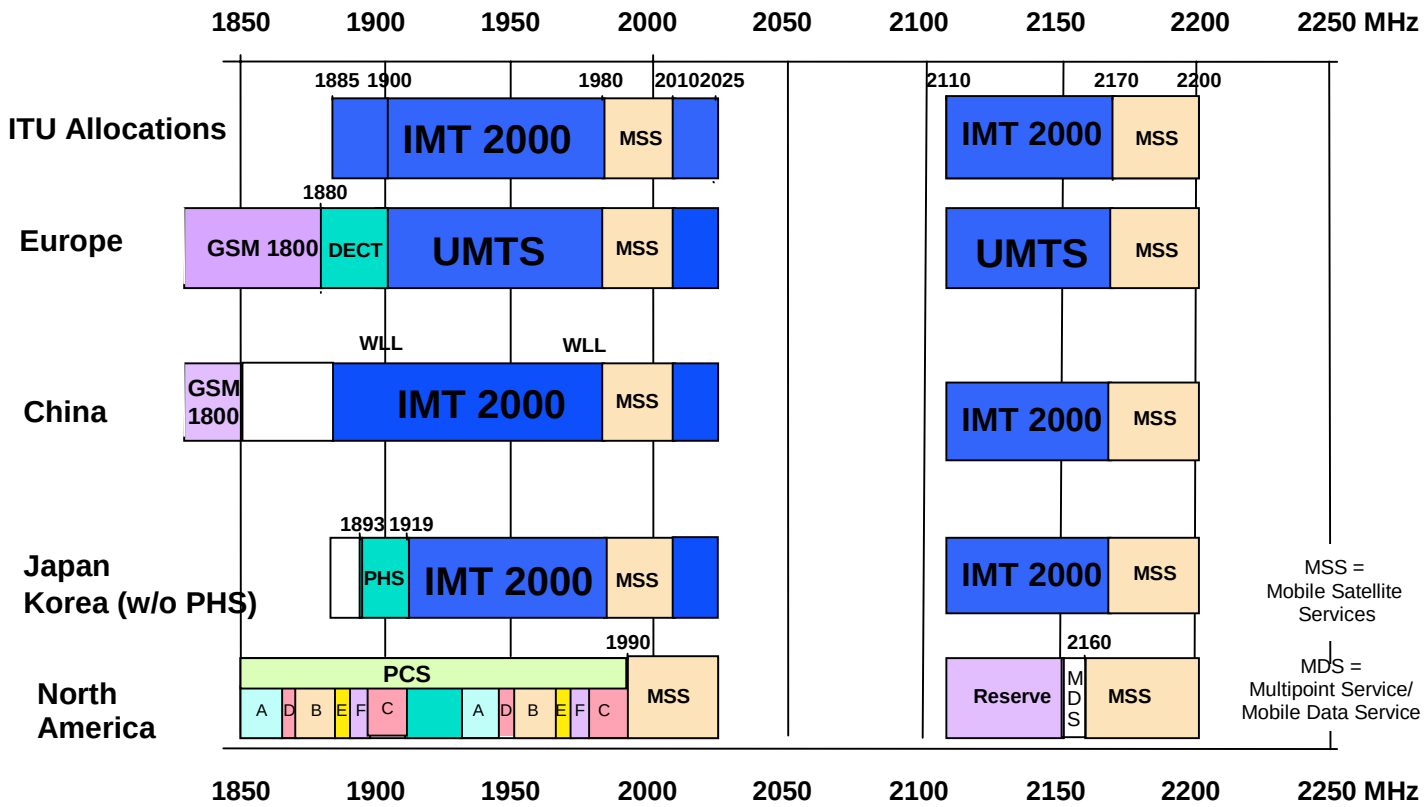




4. Very often, spectrum is paid for and exclusively allocated by the operators, but not used everywhere, at any time
5. Exclusive allocation guarantees that unwanted interference is limited, the quality of service is controlled by the operators

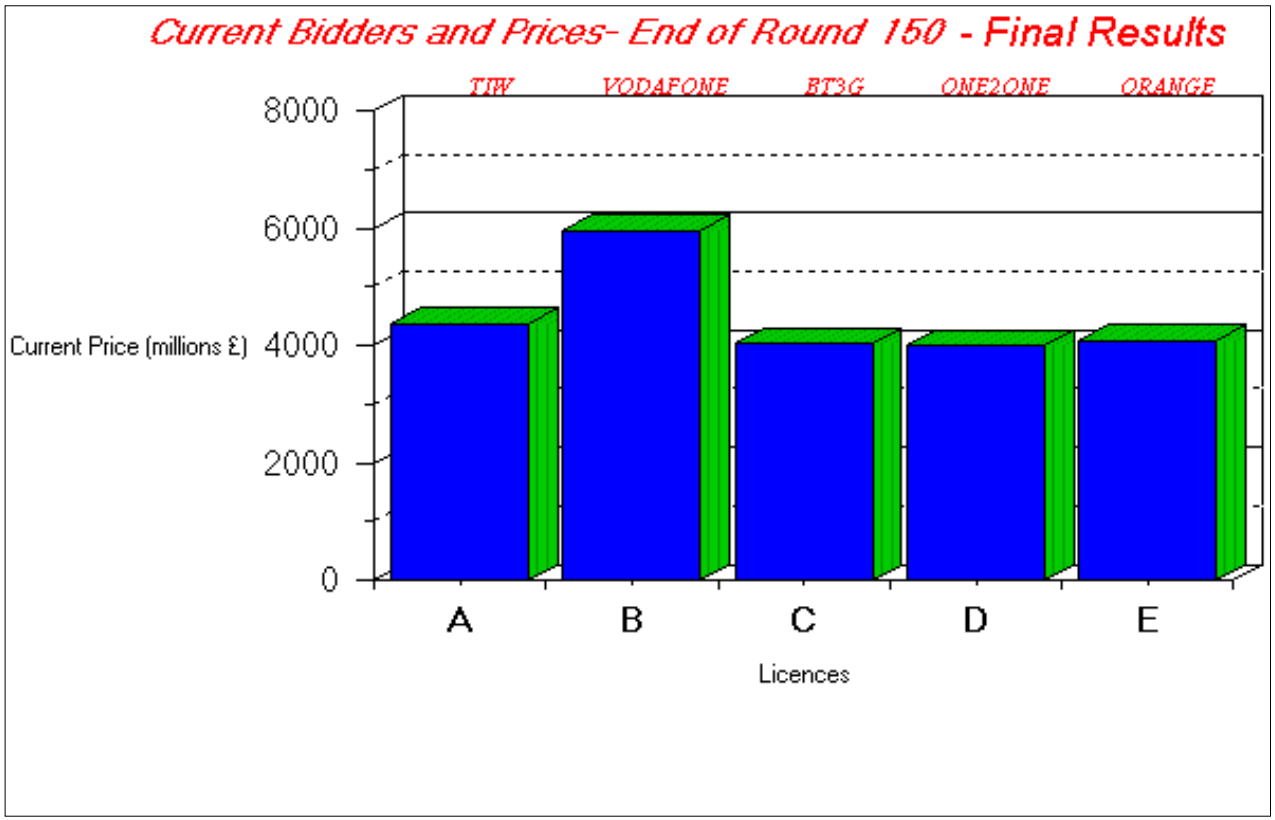
Example: European 3rd Gen. Mobile Network UMTS

Spectra, available for various operators



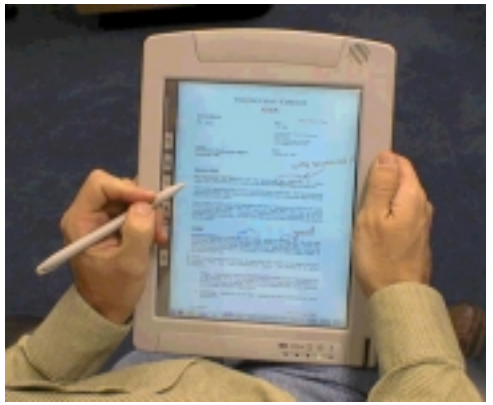
Example: European 3rd Gen. Mobile Network UMTS

Costs for licenses, U.K. only



Beyond 3rd Gen.: Autonomous Coordination

1. Increasing demand for wireless applications, more throughput per terminal, better quality (Wireless Multimedia) ⟶ even more spectrum is needed
2. The spectrum will very often be shared
3. If resources are not used, they have to be gracefully released for the advantage of the competing systems

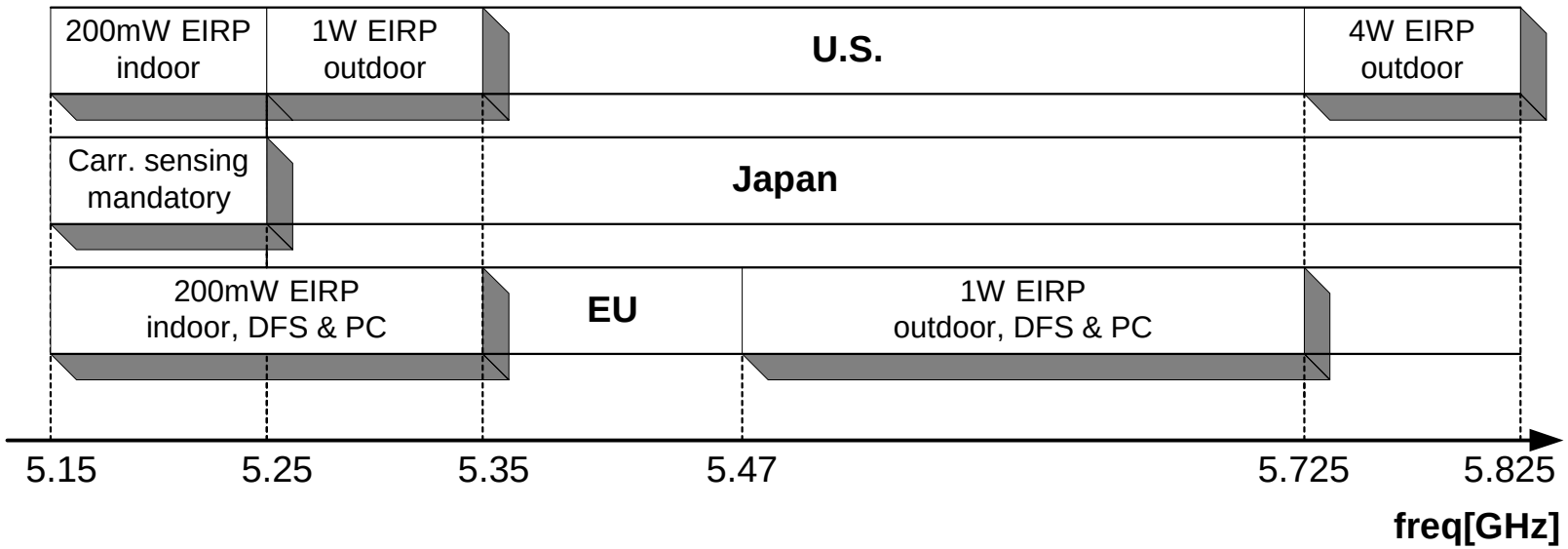


Wireless Multimedia Terminal

4. Wireless communication systems will coexist, without being able to communicate and inter-operate
5. This requires a de-central instantaneous resource management, based on local service requirements

Advantage of these systems: no exclusive license required

The 5 GHz U-NII and License Exempt Band



455 MHz will be released in Europe, 300 MHz in the U.S.

Two types of systems will operate in this band:

HiperLAN/2 and 802.11a

Europe: ETSI BRAN HiperLAN/2

The European Telecommunications Standardization Institute (ETSI), Project Broadband Radio Access Network (BRAN), released a first standard in 2000.

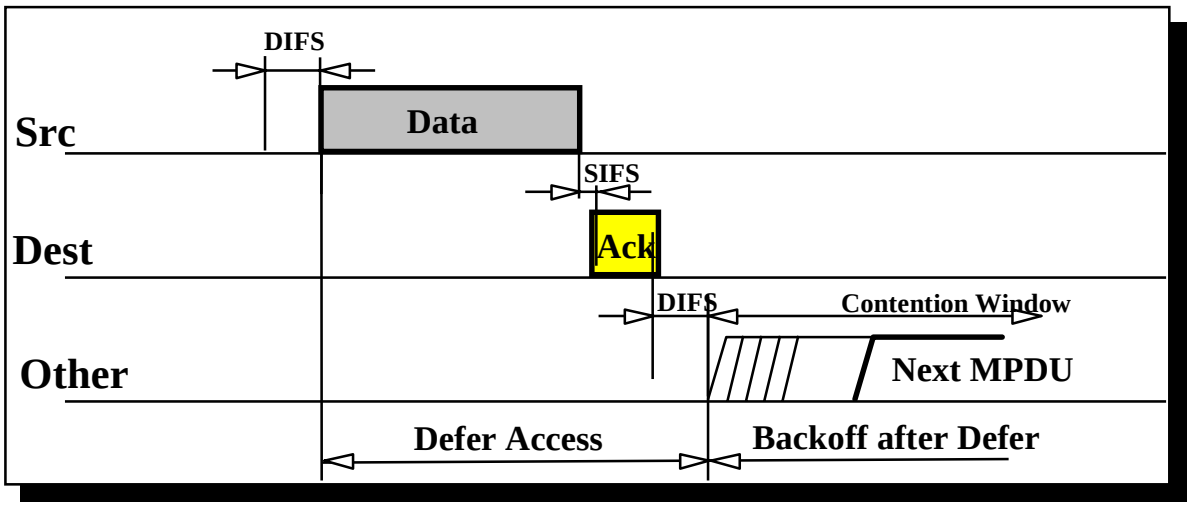
First products will be available in Europe by end of 2001.

High Performance Local Area Network

- Wireless ATM, IP, W1394, UMTS
- up to 54 Mbit/s per system
- 64pnt-OFDM transmission technique, 25 MHz per channel
- Transmission of small packets, statistical multiplexing
- Centrally controlled MAC, inherent QoS support (RR&RG)
- No compromise of QoS in ad hoc mode

U.S.A.: IEEE 802.11a

- 5 GHz „Wireless Ethernet“
- Some insufficient means to support QoS, but under discussion, CSMA/CA



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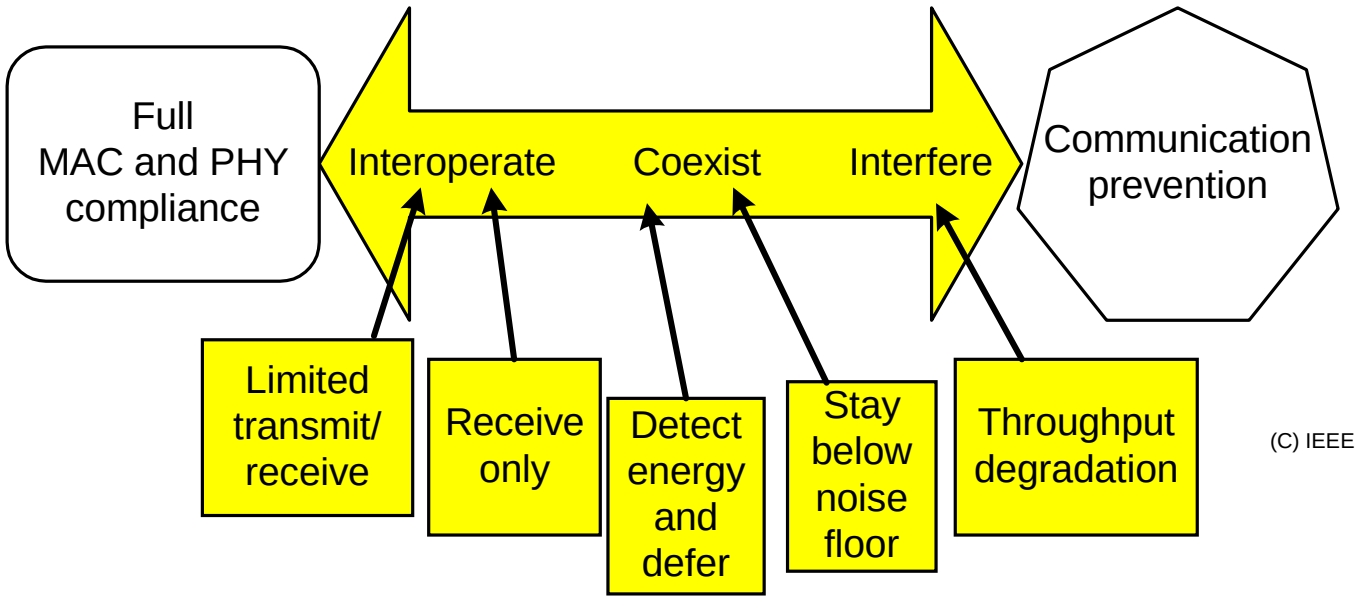
IEEE 802.11a: DCF/PCF with CSMA/CA (listen-before-talk)

In contrast to HiperLAN/2 not centrally controlled

The Problem of Coexistence and Interoperability

- 5 GHz U-NII and license exempt band
- Mandatory: graceful coexistence, fairness
- How to achieve QoS in a competitive unlicensed environment?
- Interoperability: resource management coordination (should be avoided)

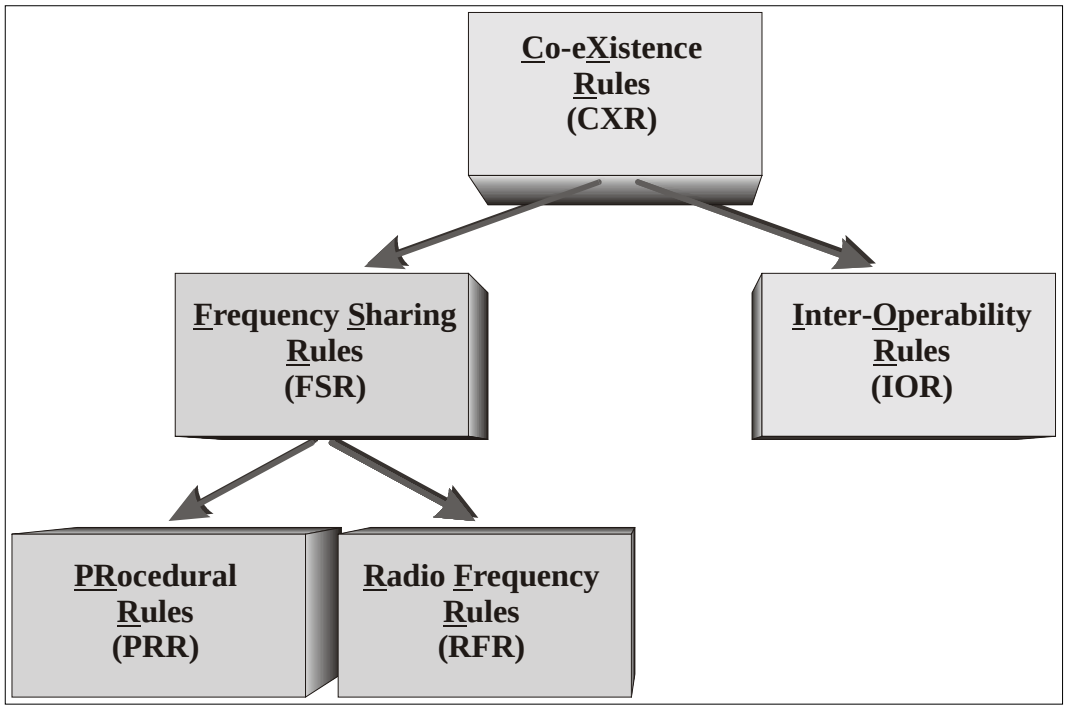
The Interoperability / Interface Continuum



Classic Frequency Sharing Rules

Rules build up an etiquette, without requiring a modification of standards

- basically accept the other competing radio system
- aim to increase spectrum efficiency in uncoordinated scenarios
- support instantaneous QoS for wireless Multimedia



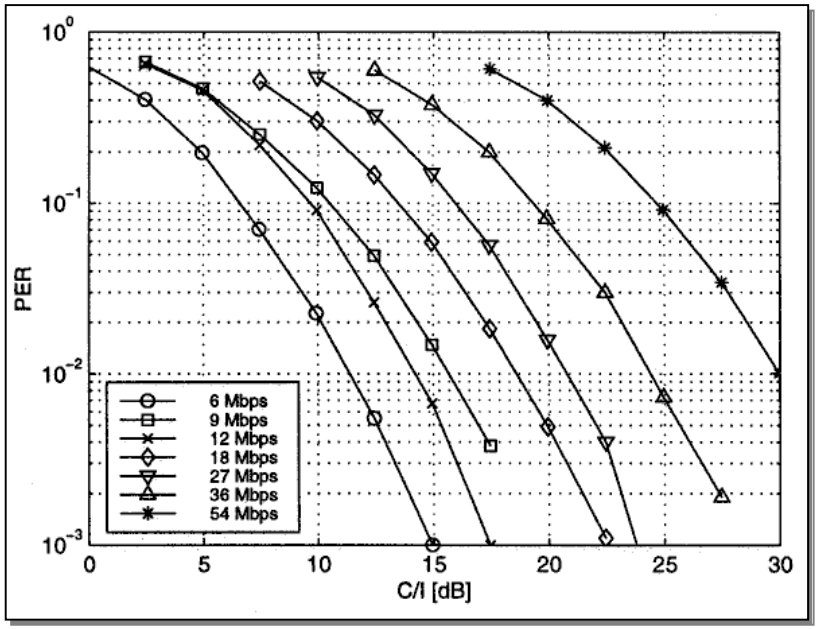
Fairness

- Resources are dynamically allocated to all systems with respect to their current requirements

Adaptive Techniques

Typical measures to reduce the mutual interference are

1. Transmitter power control
2. Adaptive PHY rate control
3. Dynamic frequency selection

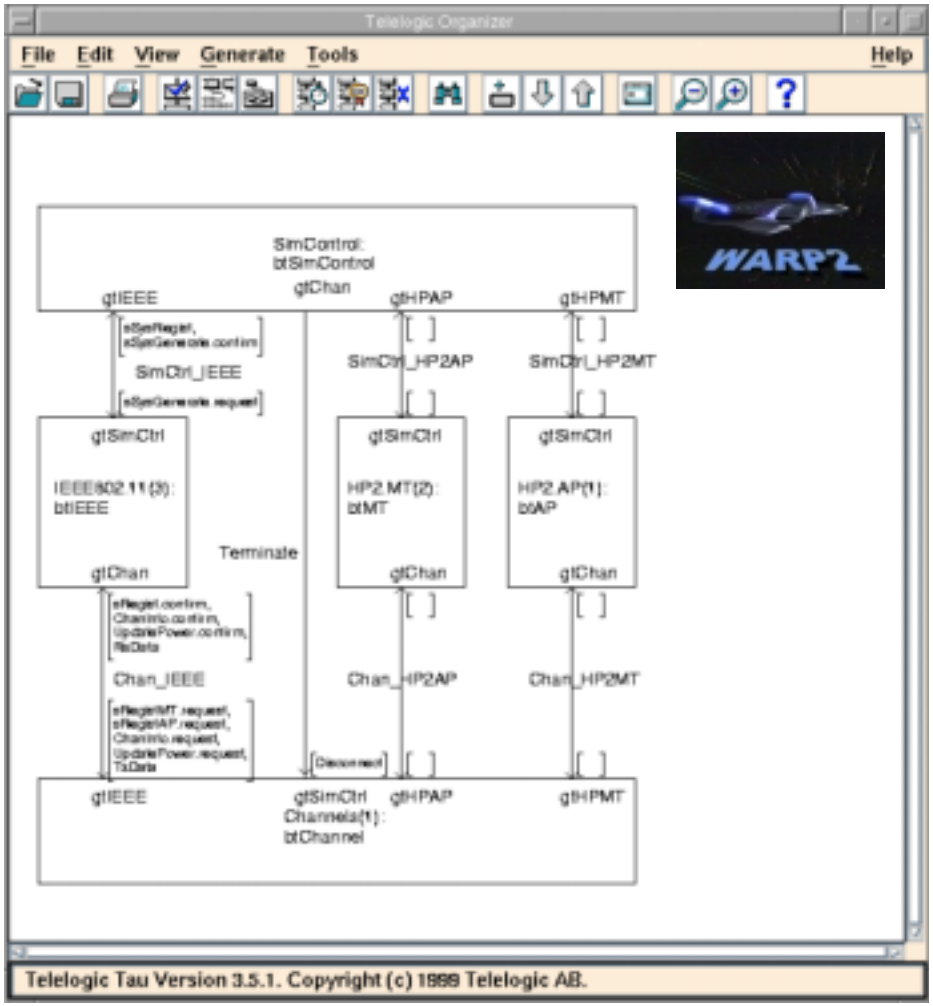


The mechanisms are standardized.

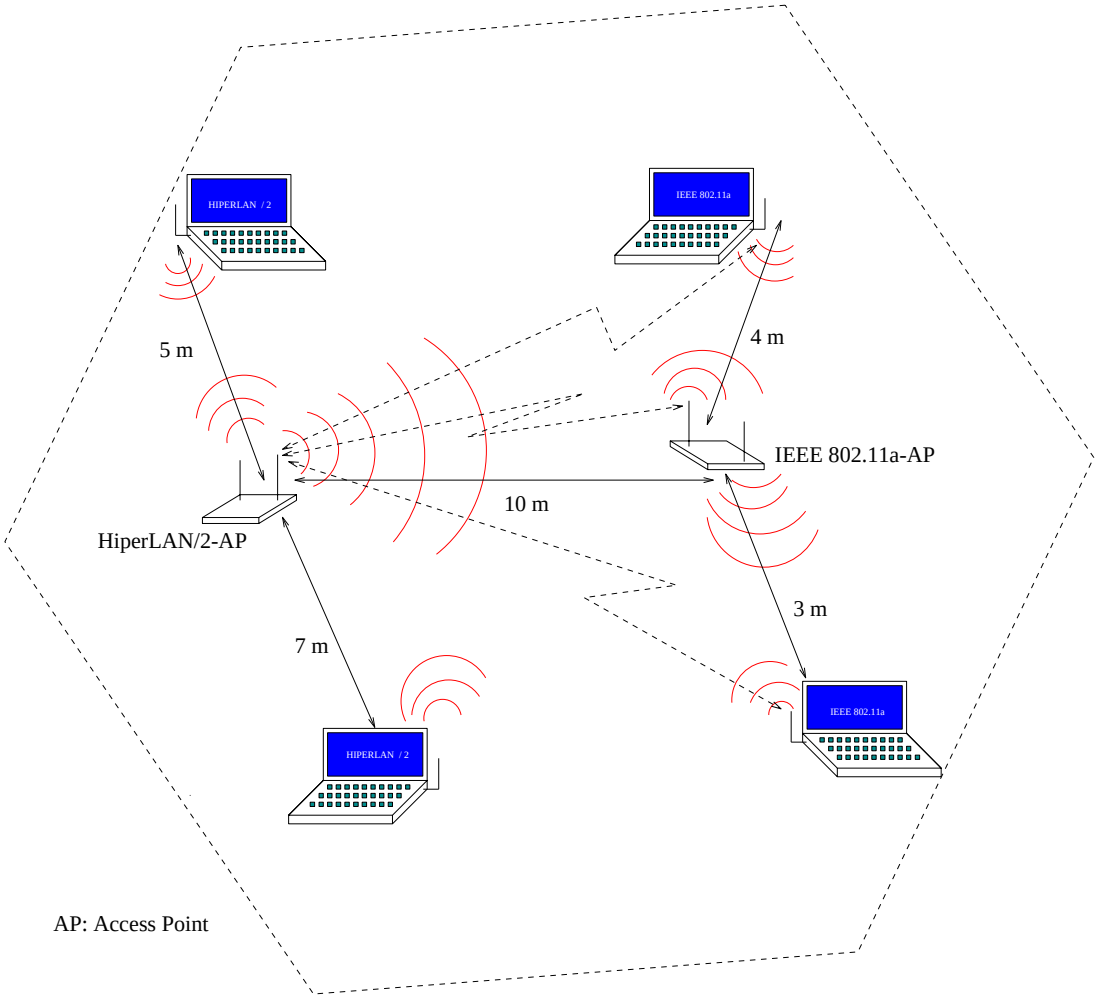
The algorithms for these techniques are not. They are up to manufacturers only.

ComNets´ WARP2 Simulation Environment

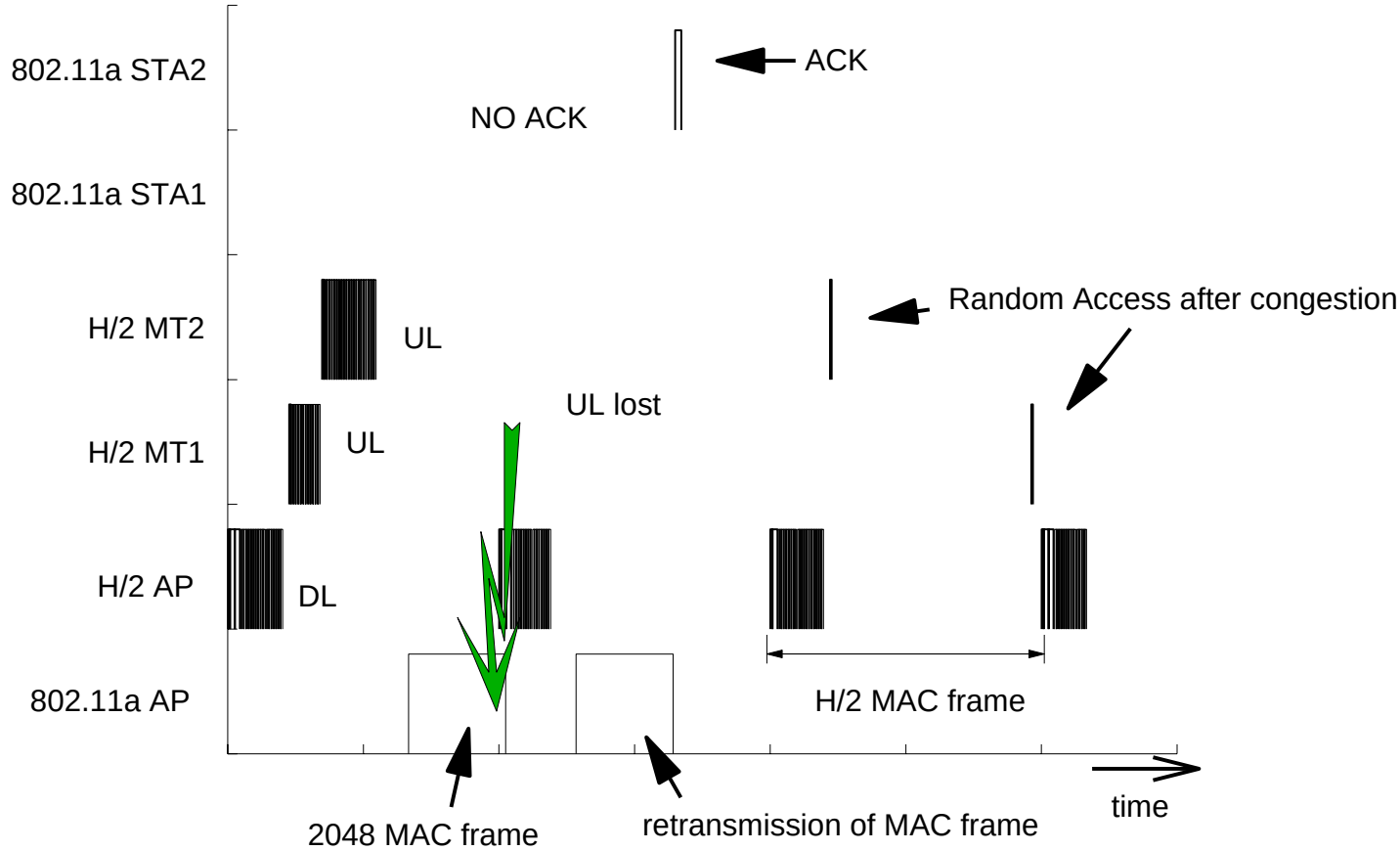
- formal specification of DLC in SDL using Telelogic´s SDT
- Mobility-, channel-, and PHY-models
- Realistic ,multimedia traffic
- Event-driven, stochastic simulation



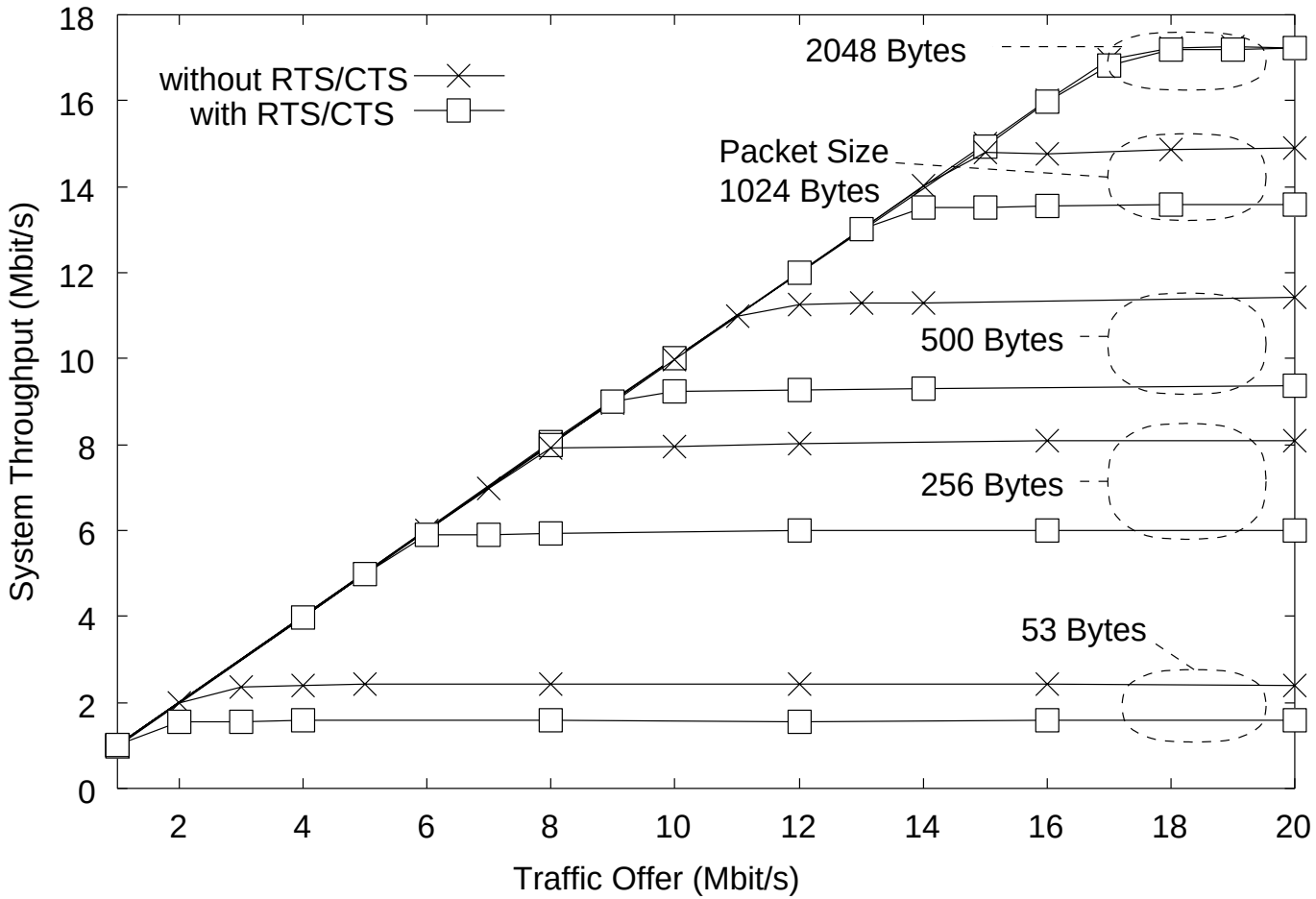
Simulation Scenario



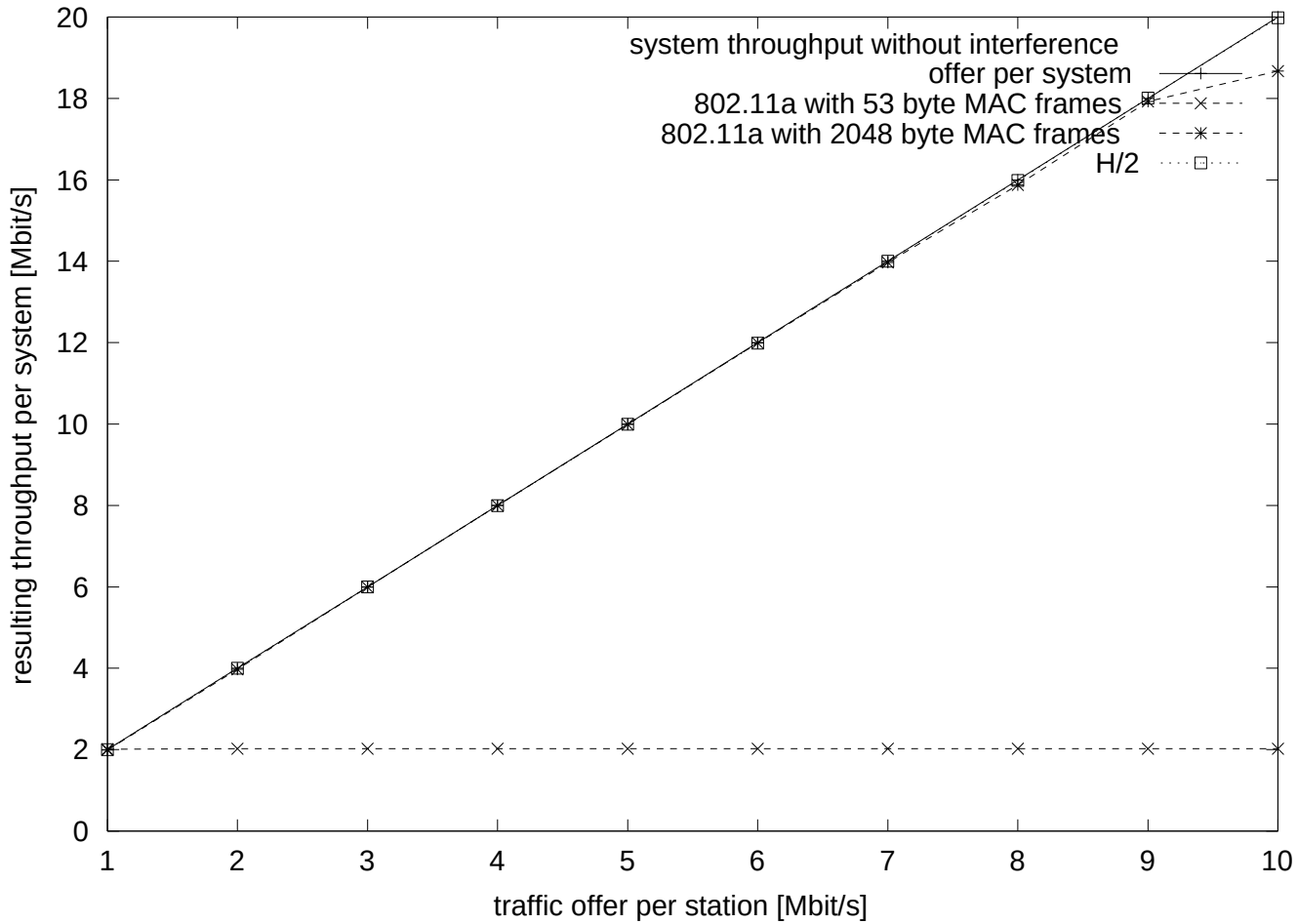
Mutual Interference



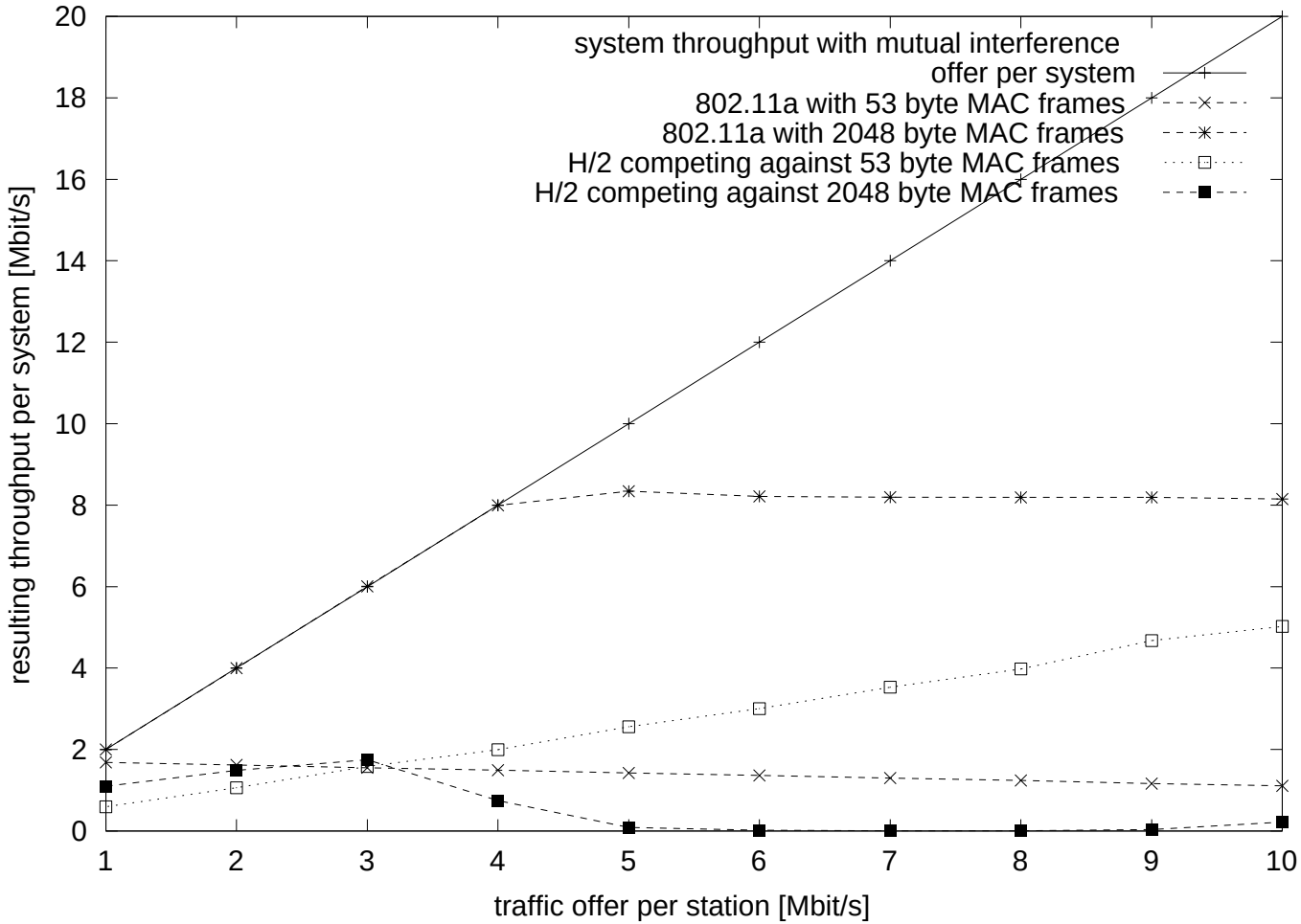
Throughput without mutual Interference (1)



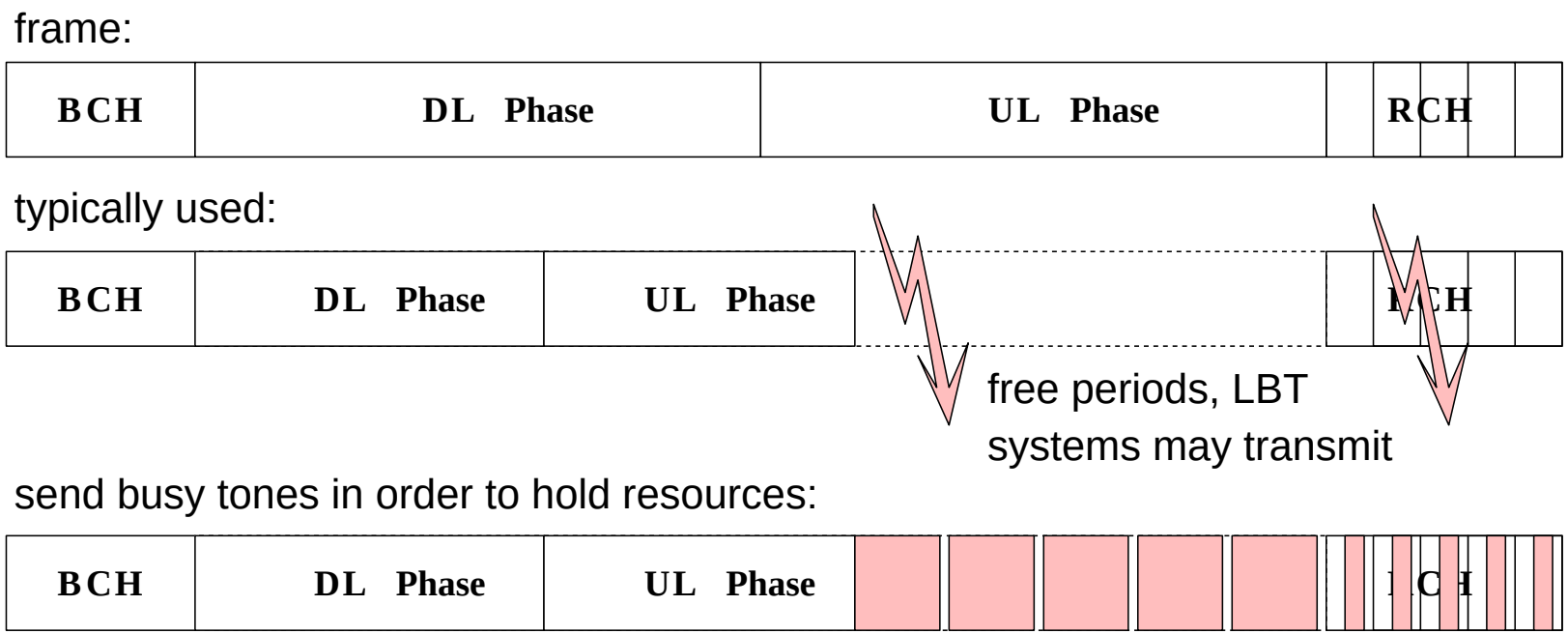
Throughput without Mutual Interference (2)



Degradation if Resource Sharing is Uncoordinated



The Busy Tone Concept



may not be fair, but is efficient

Game Theory may be the Solution?

1. In future wireless communication, de-central coordination of resource sharing is crucial
2. Cognitive Software Radio is opening new fields of research
3. Interoperability (fictious play) is not possible
4. System behaviour is rational, however
5. Scenarios including radio propagation may be simple enough for representative analytic models
6. Nash Equilibrium solutions and related work may not represent the real world scenarios?
7. Adopting Axelrod's sociologic work may be a heuristic approach?
8. Most promising: learning from observation, adaptive strategies, evolution

Game Theory:

Non-Cooperative Game Theory

Evolutionary Game Theory

The Evolution of Cooperation

Non-Cooperative Game Theory

- models of competition scenarios as a game: Stack-Hunt, Hawk-Dove, Prisoner's Dilemma
- preference relations lead to utility functions
- there are one-shot games and repeated games

- does a unique Nash Equilibrium exist? How can we reach it?
- Pareto-dominance vs. Risk-dominance: is there an achievable social optimum?
- what are the best-response strategies?
- do we apply pure and mixed strategies?

Example: The Prisoner's Dilemma

	don't confess	confess
don't confess	3,3 *both players spend only short time in prison: cooperative, social optimum*	0,4 *player two witnesses against one*
confess	4,0 *player one witnesses against two*	1,1 *three years both* *Nash Equilibrium*

Evolutionary Game Theory

- play the game repeatedly with dynamic decision taking
- the mixed strategy of a player changes
- allow mutation mechanisms (cross-over) and learning by observation (best-response)

- is there an evolutionary equilibrium?
- is the system asymptotically stable?
- are the adopted strategies evolutionary stable (survival of the fittest)?
- do we end up in the social optimum? or the local one?

The Evolution of Cooperation

- taken from social science: experiments by Axelrod
  - •act fair and nice, allow cooperation first of all
  - •act simple, the others need to understand and anticipate you!
  - •act provokable and irritable when opponent does not cooperate
  - •act forgiving after striking back

- how to convince the others to play specific strategies without communication?
- problem with that: sometimes very heuristic, analytic models fail!
- fundamental statement: cooperative players operating in a cooperative environment perform most successful

Conclusion: Loads of Open Questions !!!

1. The market is large, the requirement is there
2. The coexistence problem appears to be unsolved
3. We are developing Yahoos only, we waste our expensive spectrum

<u>In contrast:</u>

4. Game Theory is established in neo-classical economics to model competitive resource sharing scenarios
5. Game Theory has been successfully applied in fixed network flow control, call-admission and routing analysis
6. First extensions to wireless communications are approaching (WINLAB, NJ., U.S.A.)

<u>Conclusion:</u>

7. So why not start to develop / adopt the models known from Game Theory?