Design a Cross-Layer Cognitive Engine using Cross-Layer Optimization with Case-Based Reasoning and Reinforcement Learning

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Motivation

- Efficiently usage of spectrum
- Avoiding interfering with PUs
- Fast CR's link adaptation according to channel behavior
- Ensure QoS at CR
- Autonomous reconfiguration
- Speed up action process
  - Fast convergence
  - Repeat previous actions
  - Re-evaluate actions

Outline

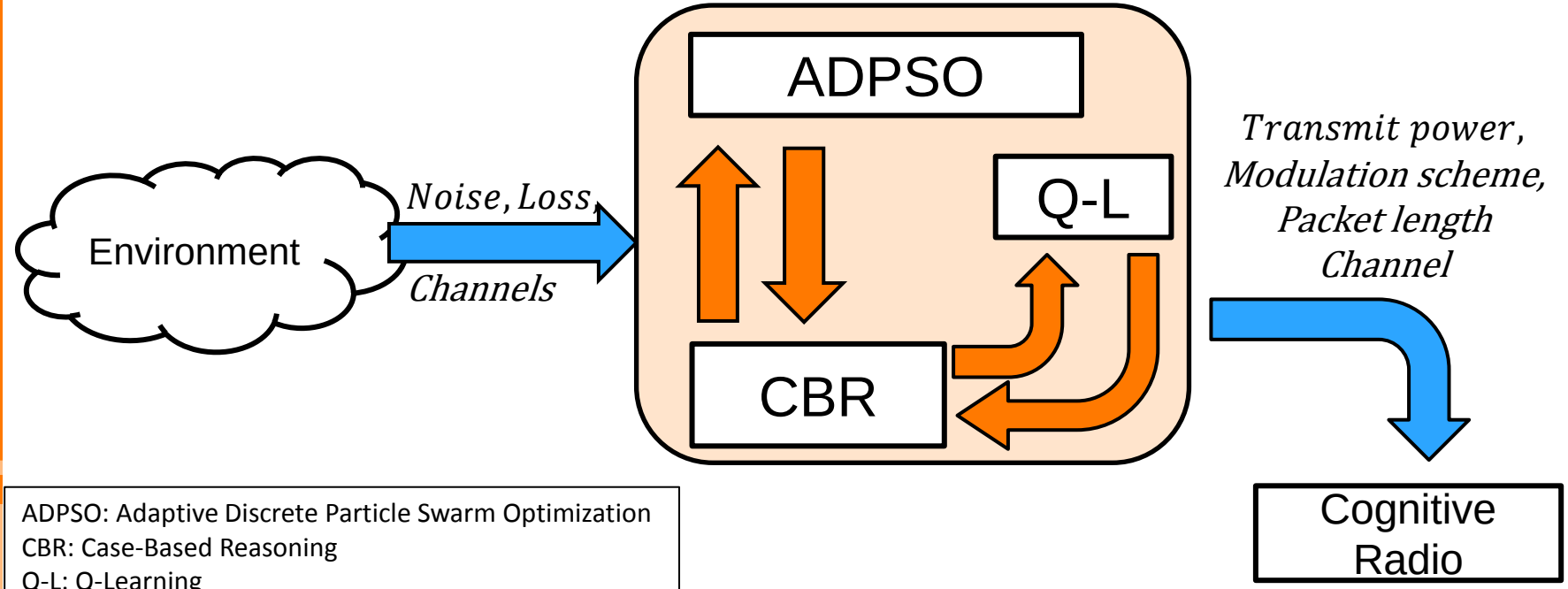
- State of the Art
- Proposed approach:
  - ADPSO
  - CBR
  - Q-Learning
- Simulation scenario
- Evaluation
- Conclusion

State of the Art

Previous Work	Adv.	Disadv.
Cognitive system monitor [1]	- Using GA for optimum output - Using Learning from previous action	- Limited Cross-Layer capability - Physical layer objectives - Limited learning process
Learning and inference system [2]	- Inference and learning based on BN	- No Cross-Layer capability - Single Objective (Bit Error Rate) - Single input parameter (SNR)
Access network [3]	- Cross layer capability - L2 – L7 application	- No learning from previous actions - FLC has difficult knowledge acquisition
Link adaptation [4]	- Fast decision making	- No Cross-Layer capability - No learning process - Physical layer objectives

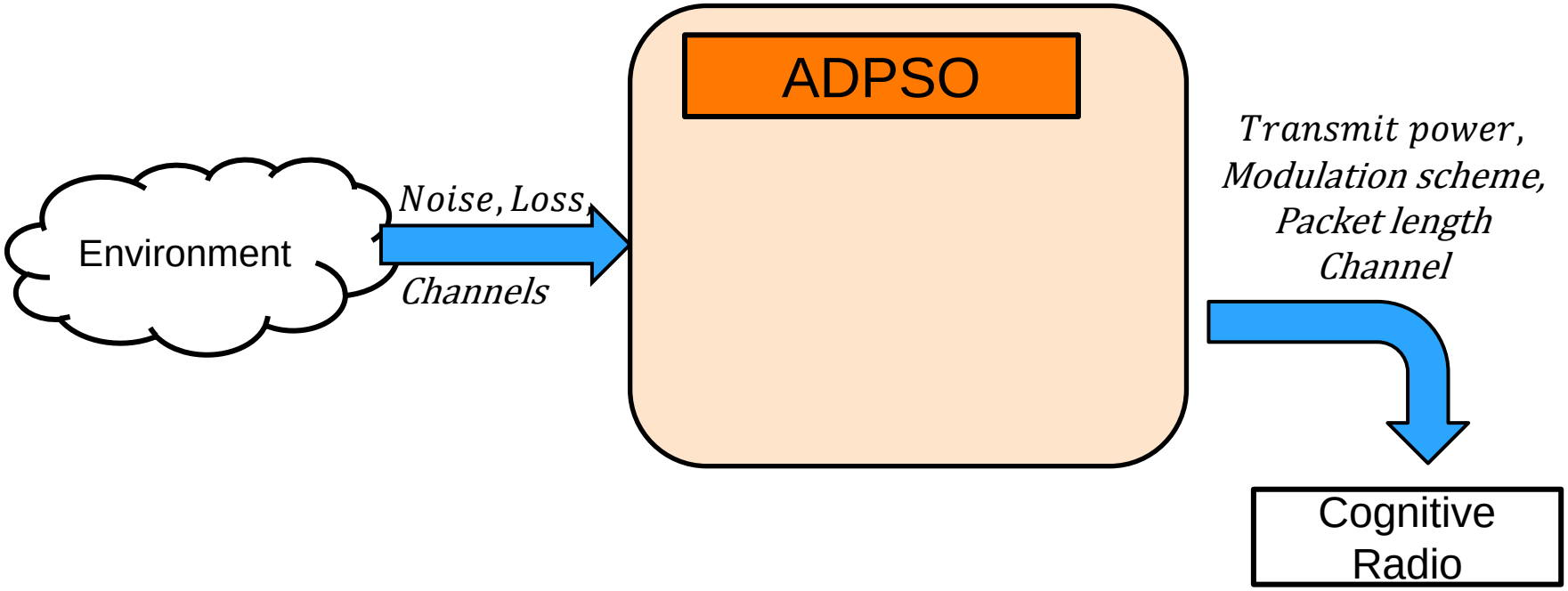
Proposed approach

- Combination: ADPSO, CBR, Q-L
  - ADPSO: proposes link configuration
  - CBR: selects previous link configuration
  - Q-L: Update previous link configuration's score



ADPSO: Adaptive Discrete Particle Swarm Optimization
CBR: Case-Based Reasoning
Q-L: Q-Learning

Proposed approach: ADPSO



A. Mahdi, J. Mohanen, M. Kalil, A. Mitschele-Thiel, "Adaptive Discrete Particle Swarm Optimization for Cognitive Radios", IEEE ICC '12, Ottawa, Canada, June 2012.

A. Mahdi, M. Kalil, A. Mitschele-Thiel, "Cross-Layer Optimization for Efficient Spectrum Utilization in Cognitive radios", ICNC 2013, San Diego, USA, January 2013.

Proposed approach: ADPSO

- Adaptive Discrete Particle Swarm Optimization (ADPSO):
  - Divide fitness space into four regions
  - Modify the velocity coefficients (c_1 , c_2 , w) according to fitness value

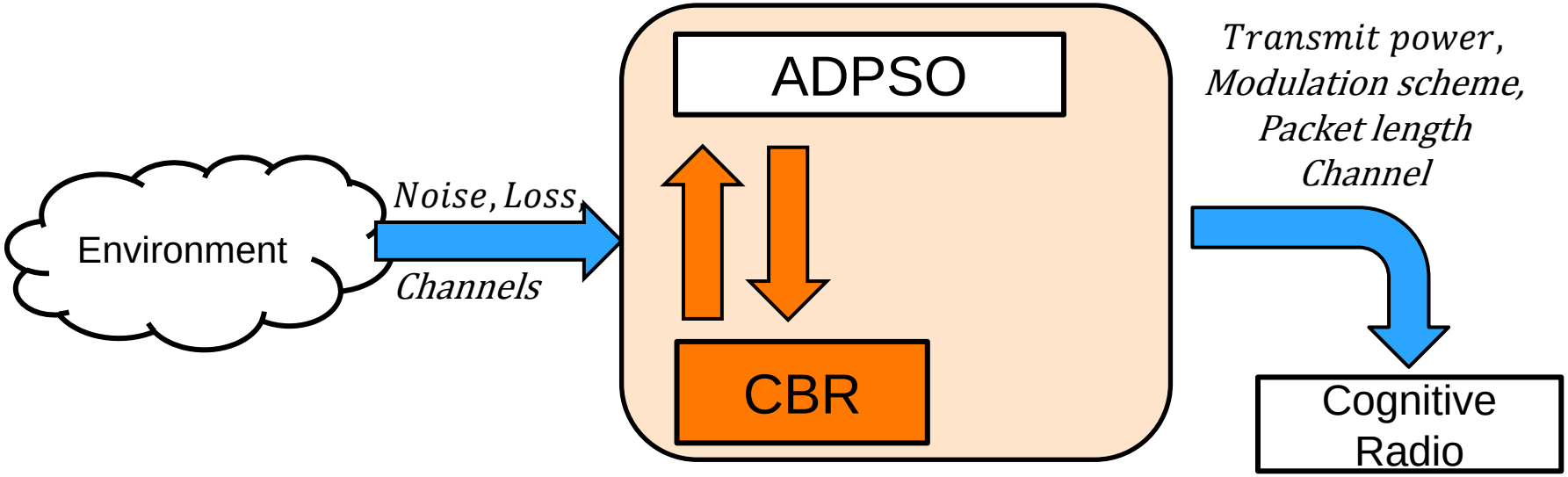
Regions	Fitness	C_1	C_2
Jump-out	0 – 0.2	- 0.1	+ 0.1
Exploration	0.2 - 0.4	+ 0.1	- 0.1
Exploitation	0.4 – 0.6	+0.05	- 0.05
Convergence	0.6 – 1.0	- 0.05	+ 0.05

$$W(fitness) = \frac{1}{(1+1.5\times e^{-2.6 fitness})}$$

  - Implements Elitist Learning Strategy (ELS)

Proposed approach: CBR

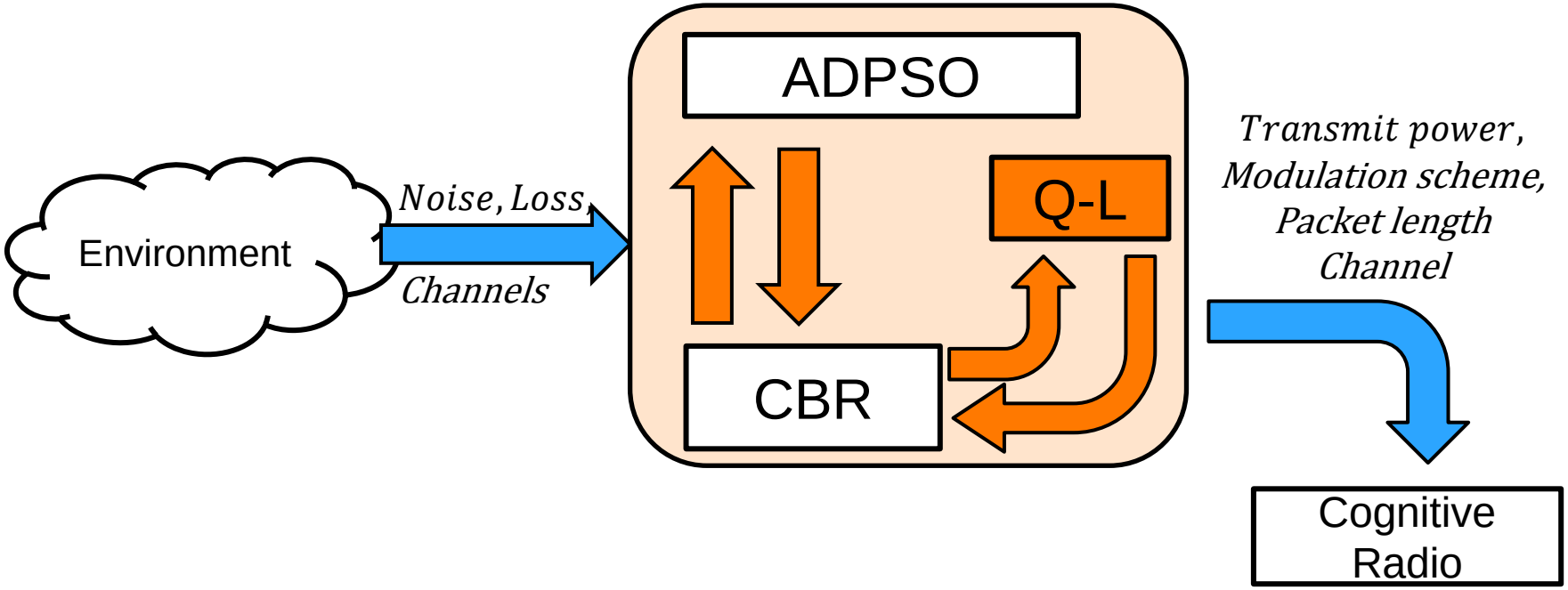
- Case-Based Reasoning (CBR):
  - Implement past experience
  - Speed up convergence
  - Reduce computation efforts



A. Mahdi, M. Kalil, A. Mitschele-Thiel, "Dynamic Packet Length Control for Cognitive Radio Networks", VTC2013-Fall, Las Vegas, USA, September 2013.

Proposed approach: Q-Learning

- Q-Learning(Q-L):
  - Study the history of channels
  - Learn appropriate action



Proposed approach: Q-Learning

- Q-L:
  - Select similar previous (state-decision) pairs

Ch	Noise	Loss	Pt	M	L	fitness
4	-100	90	25	QPSK	600	0.75
2	-110	85	20	8PSK	700	0.78
1	-95	88	30	8PSK	850	0.82

Proposed approach: Q-Learning

- Q-L:
  - Select similar previous (state-decision) pairs
  - Evaluate current fitness at Tx and Rx

Ch	Noise	Loss	Pt	M	L	fitness
4	-100	90	25	QPSK	600	0.75
2	-110	85	20	8PSK	700	0.78
1	-95	88	30	8PSK	850	0.82

Proposed approach: Q-Learning

- Q-L:
  - Select similar previous (state-decision) pairs
  - Evaluate current fitness at Tx and Rx
  - Update total fitness + Rewards

Ch	Noise	Loss	Pt	M	L	fitness	
4	-100	90	25	QPSK	600	~~0.75~~	0.82
2	-110	85	20	8PSK	700	~~0.78~~	0.85
1	-95	88	30	8PSK	850	~~0.82~~	0.7

Proposed approach: Q-Learning

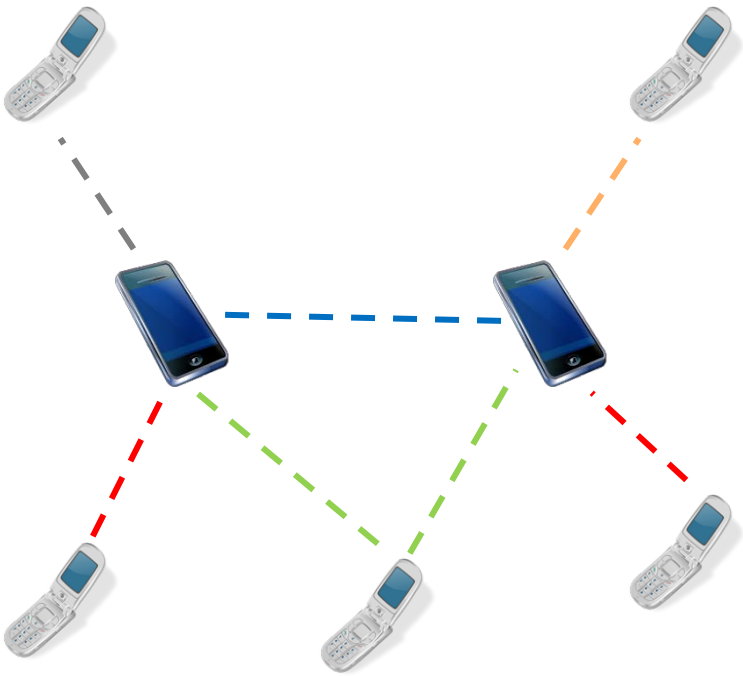
- Q-L:
  - Select similar previous (state-decision) pairs
  - Evaluate current fitness at Tx and Rx
  - Update total fitness
  - Select best decision (higher fitness)

Ch	Noise	Loss	Pt	M	L	fitness	
2	-110	85	20	8PSK	700	~~0.78~~	0.85

Simulation Scenario

Simulation parameters:

Parameter	Value	
No. of channels	5	Environmental Inputs
Channel bandwidth	100 kHz	
CCC	1	
PU arrival	0.1 -1.5 ms	
Noise (dBm)	-85 to -100	
Path loss (dB)	80 to 90	
Min. Data Rate (kbps)	100	QoS Req.
Max. Bit Error Rate	10^{-4}	
Transmit power (dBm)	0 - 25	Outputs
Modulation scheme	PSK	
Modulation index	1, 2, 3, 4	
Packet length (Byte)	100 - 1000	



Simulation scenario (cont.)

Metrics:

- Total fitness

f_1 - maximum achievable throughput

f_2 - minimum achievable delay

f_3 - channel availability

f_4 - packet loss probability

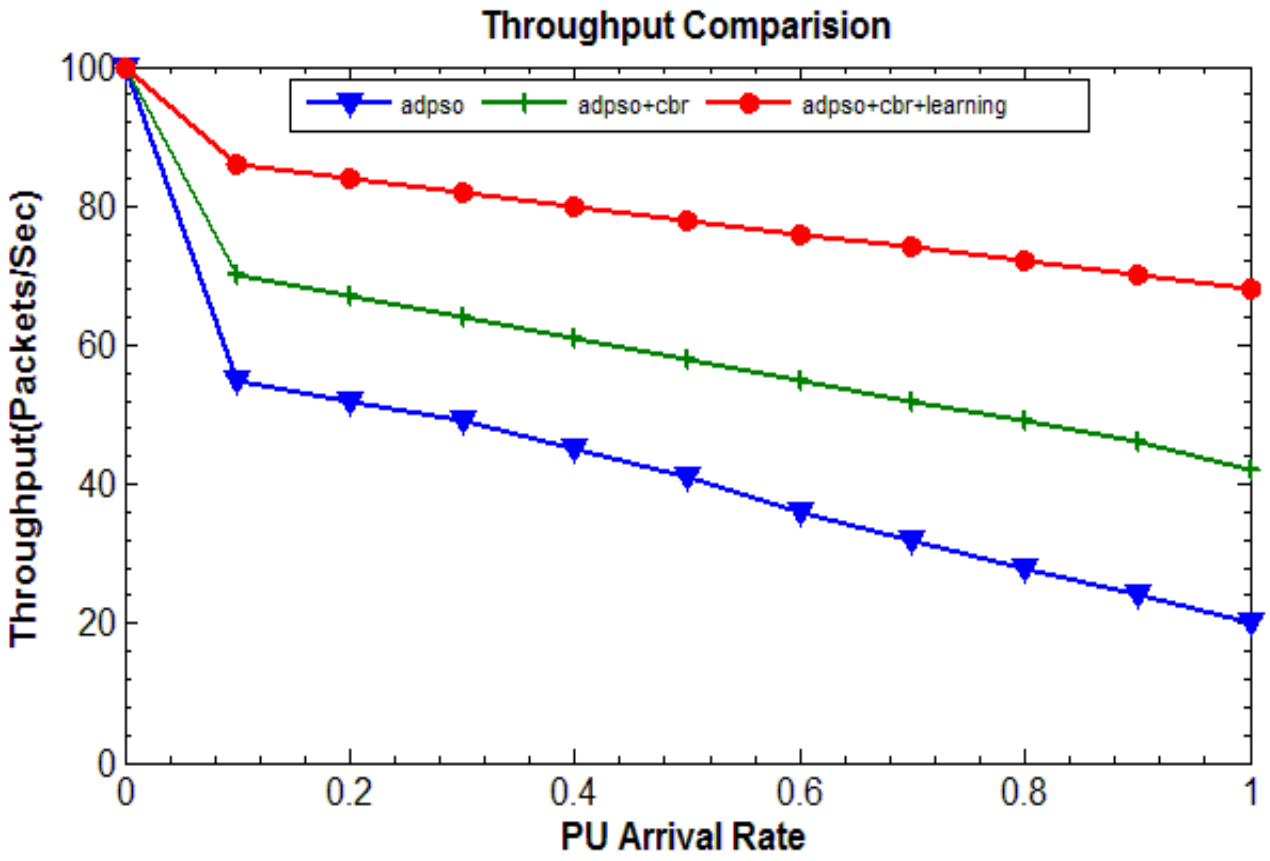
$w_1 = 0.7,\ w_2 = 0.1, w_3 = 0.1\ , w_4 = 0.1$

$$f_{total} = w_1 f_1 + w_2 f_2 + w_3 f_3 + w_4 f_4$$

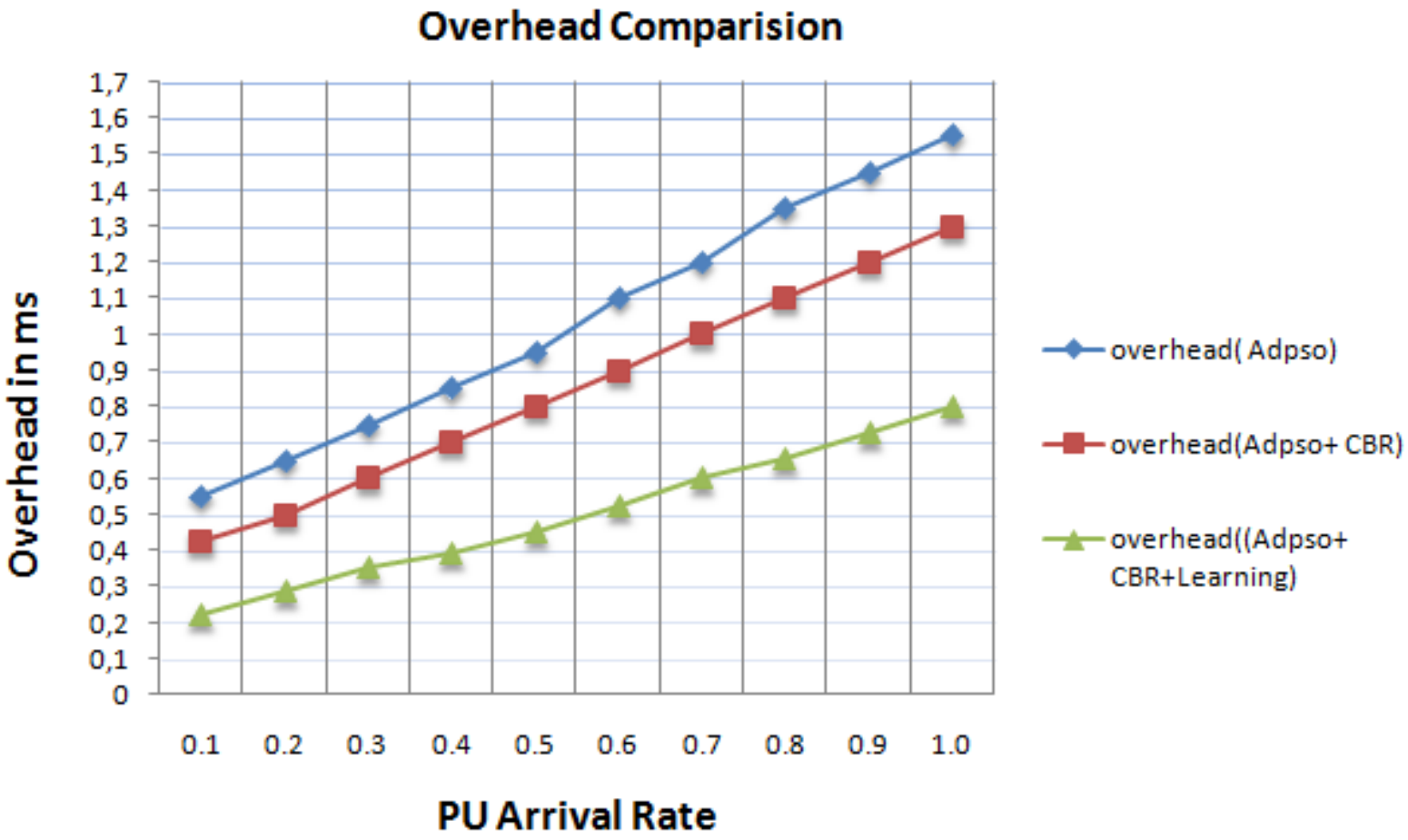
[0,1]

- Signaling overhead
- Throughput
- Channel usage

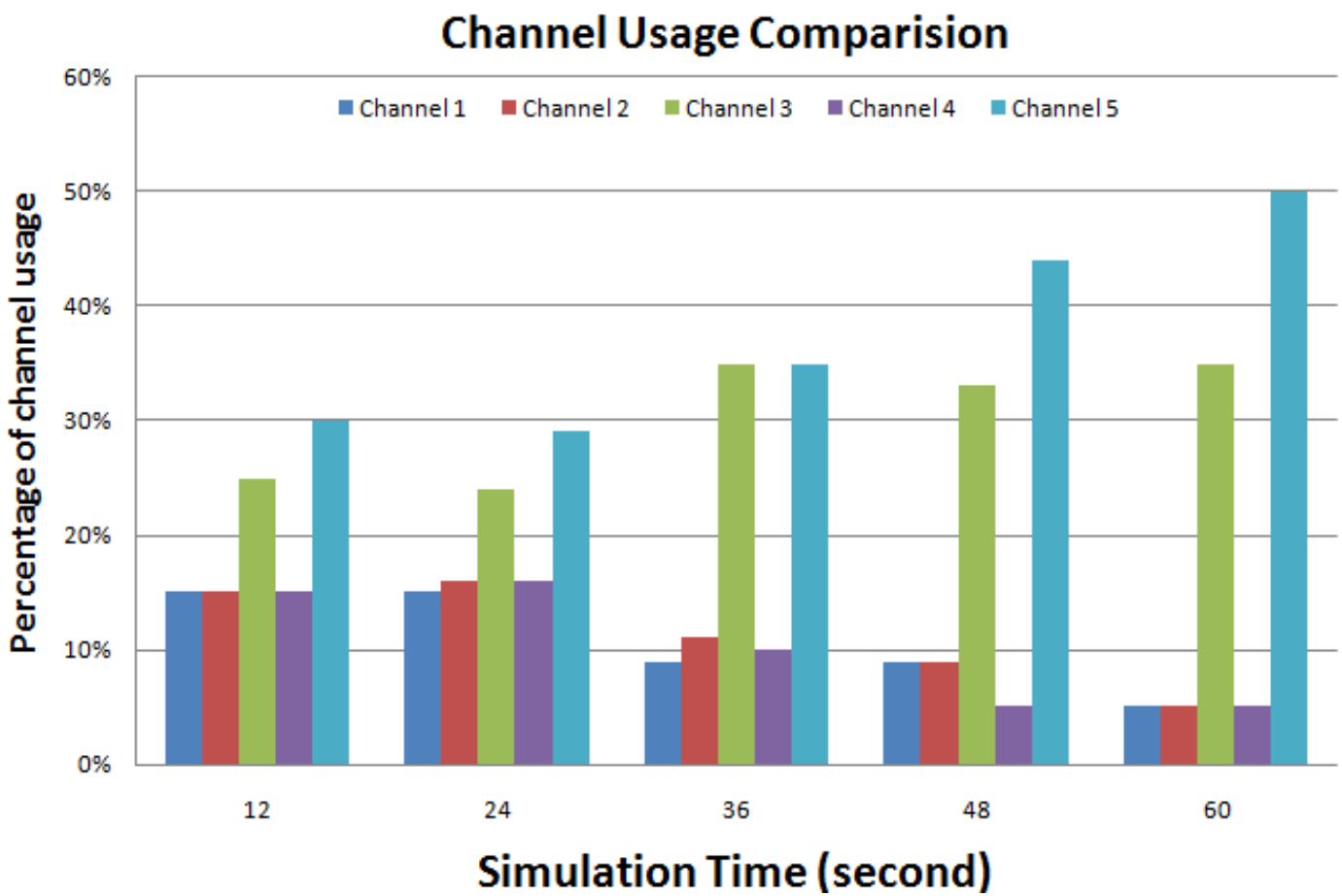
Evaluation: Throughput



Evaluation: Signaling overhead



Evaluation: Channel Usage



Conclusion

- Efficient algorithm for dynamic environment
- Fast autonomous link adaptation
- Low signaling overhead
- Higher throughput
- Best channel selection

References

[**1**] C. Reiser, “Biologically inspired Cognitive radio Engine model Utilizing Distributed Genetic Algorithm for Secure and Robust Wireless Communications and Networking”, Ph.D thesis, Virginia University, 2004.

[**2**] Y. Huang, J. Wang, H. Jiang, “Modeling of Learning Inference and Decision Making Engine in Cognitive Radio”, Second International Conference on Network Security, Wireless Communications, and Trusted Computing, 2010.

[**3**] N. Baldo, M. Zorzi, “Cognitive Network Access using Fuzzy Decision Making”, IEEE Transactions on Wireless Communications, Vol. 8, No. 7, July 2009.

[**4**] Z. Zhao, S. Xu, S. Zheng, and J. Shang, “Cognitive radio adaptation using particle swarm optimization,” *Wireless Communications & Mobile Computing*, vol. Volume 9, no. 7, pp. 875–881, July 2009.

Thank you for your attention
Questions?? Comments!!!

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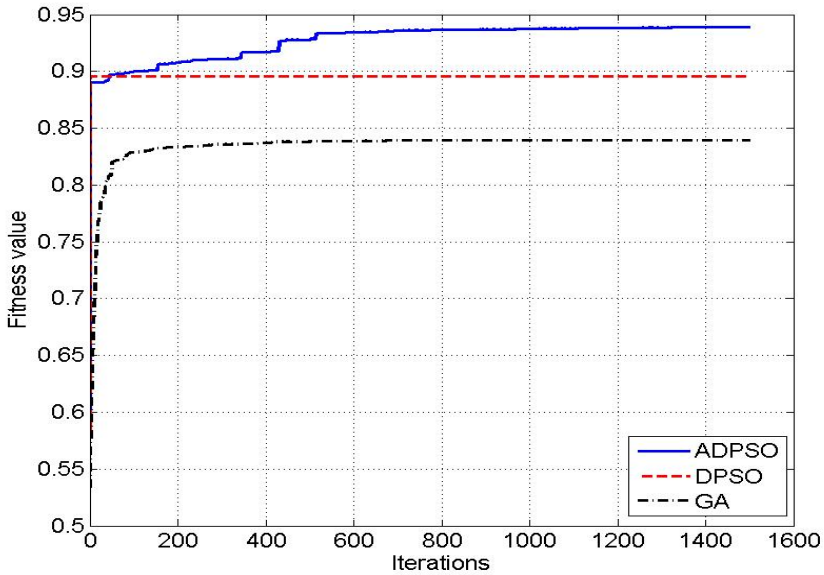
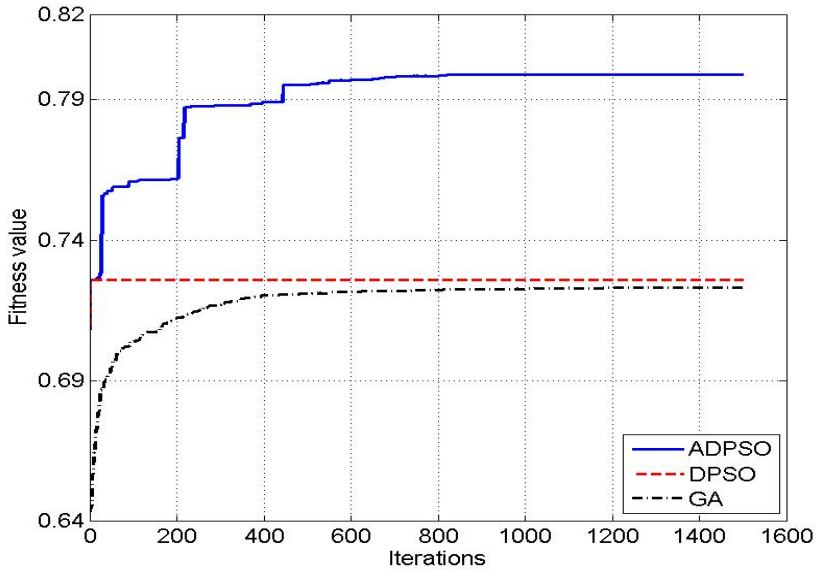
Optimization (cont.)

- Evaluation:



Maximum R_b

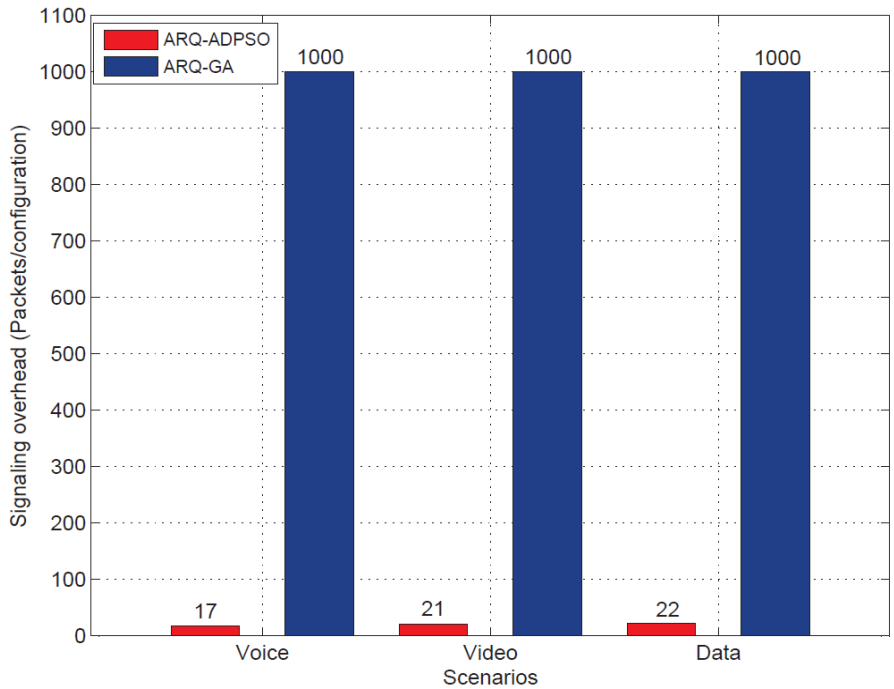


Minimum BER

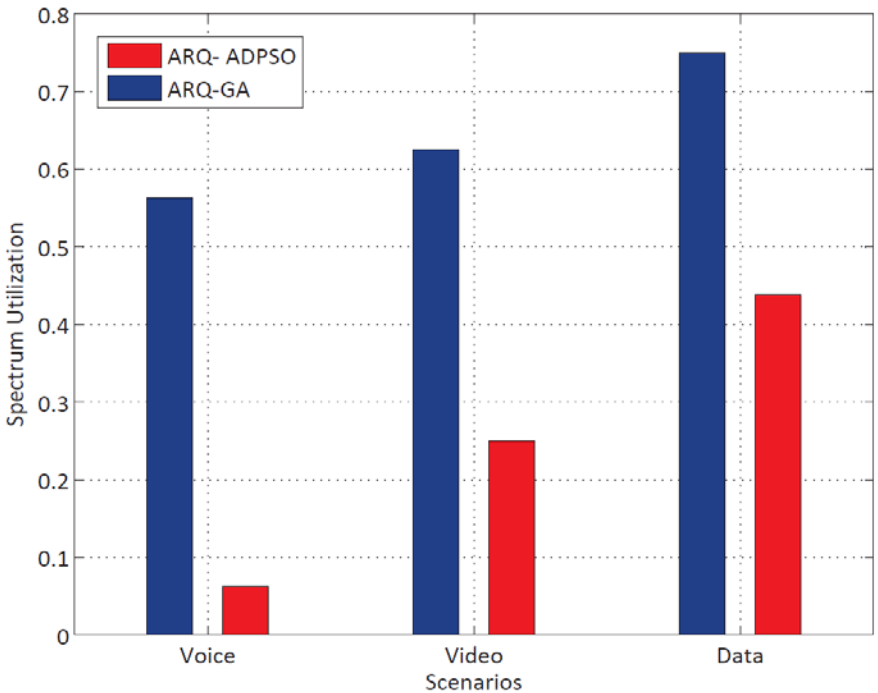
A. Mahdi, J. Mohanen, M. Kalil, A. Mitschele-Thiel, "Adaptive Discrete Particle Swarm Optimization for Cognitive Radios", IEEE ICC '12, Ottawa, Canada, June 2012.

Optimization (cont.)

- Evaluation:



Signaling overhead

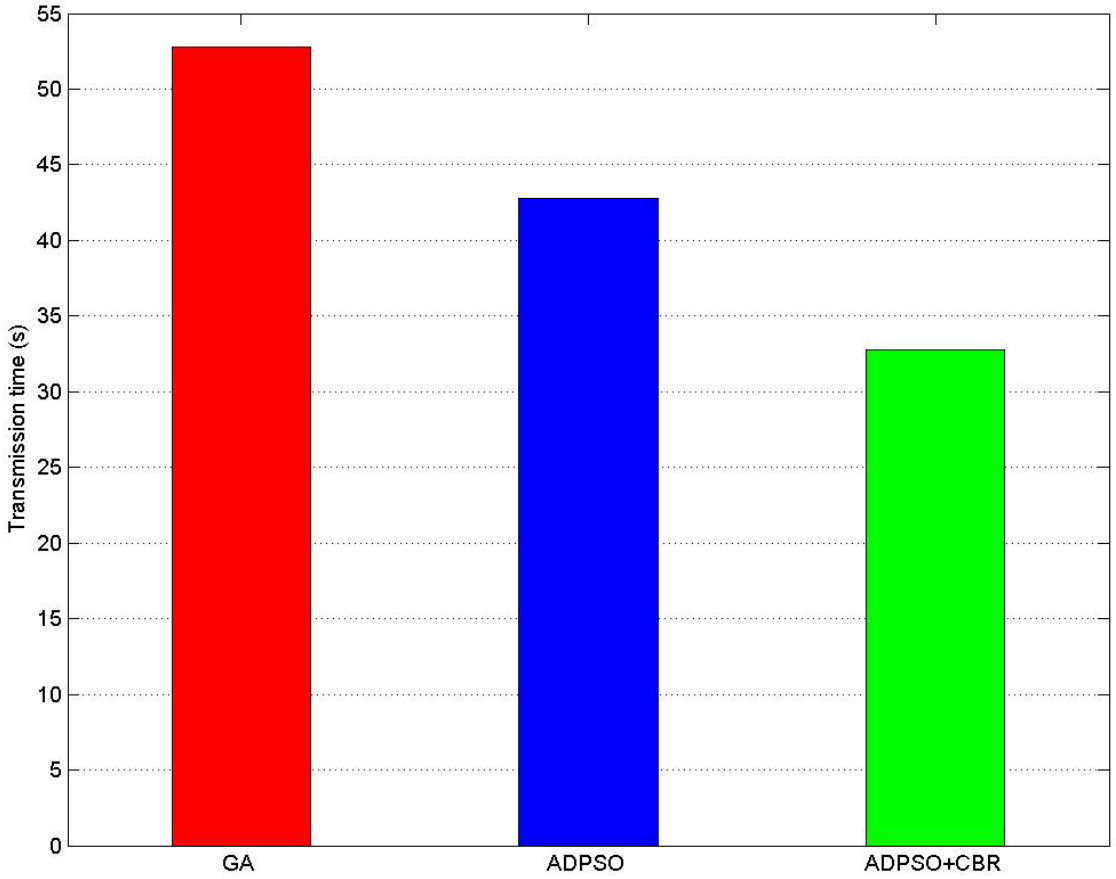


Spectrum utilization

A. Mahdi, M. Kalil, A. Mitschele-Thiel, "Cross-Layer Optimization for Efficient Spectrum Utilization in Cognitive radios", ICNC 2013, San Diego, USA, January 2013.

Reasoning (cont.)

- Evaluation:



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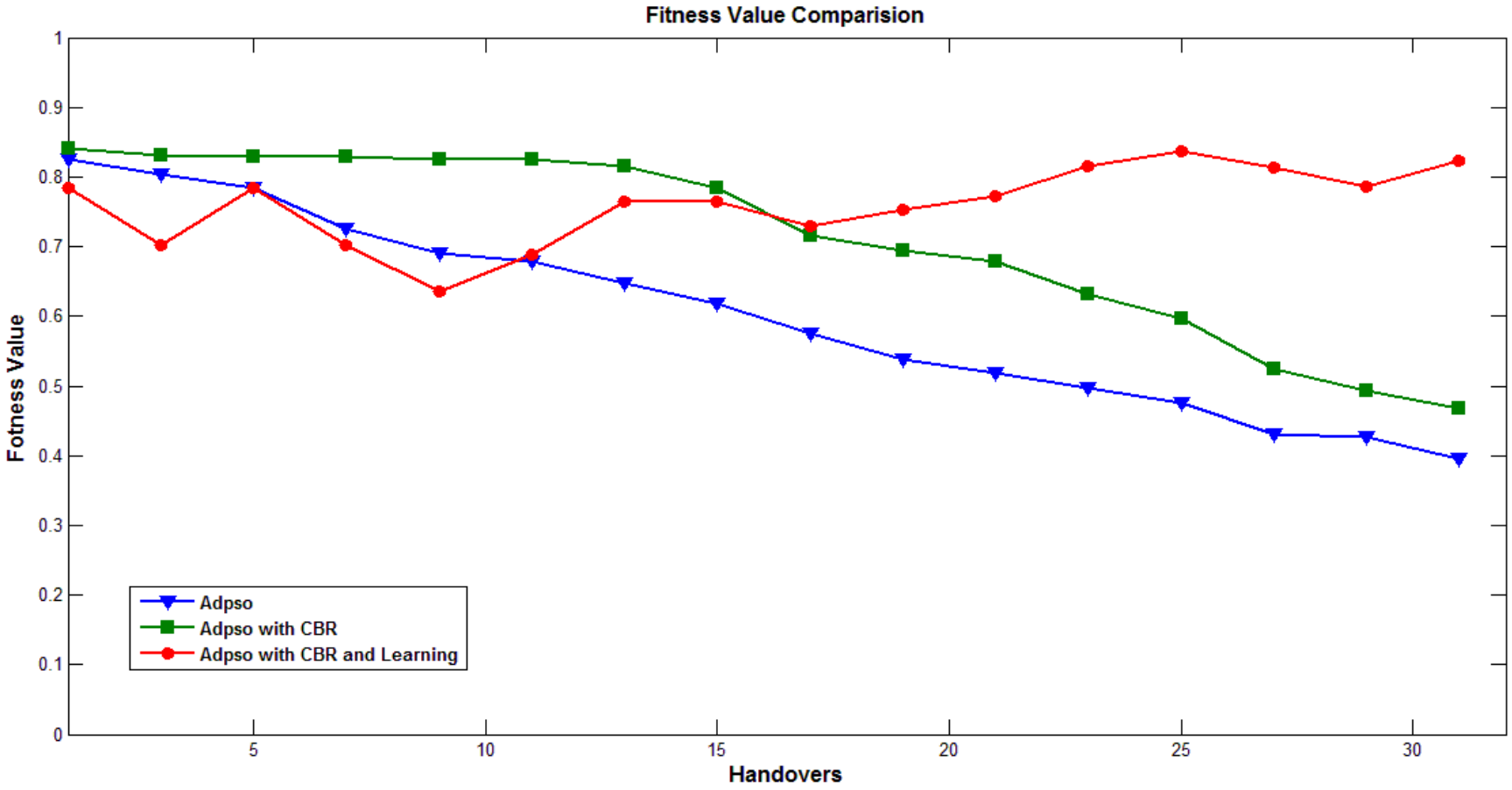
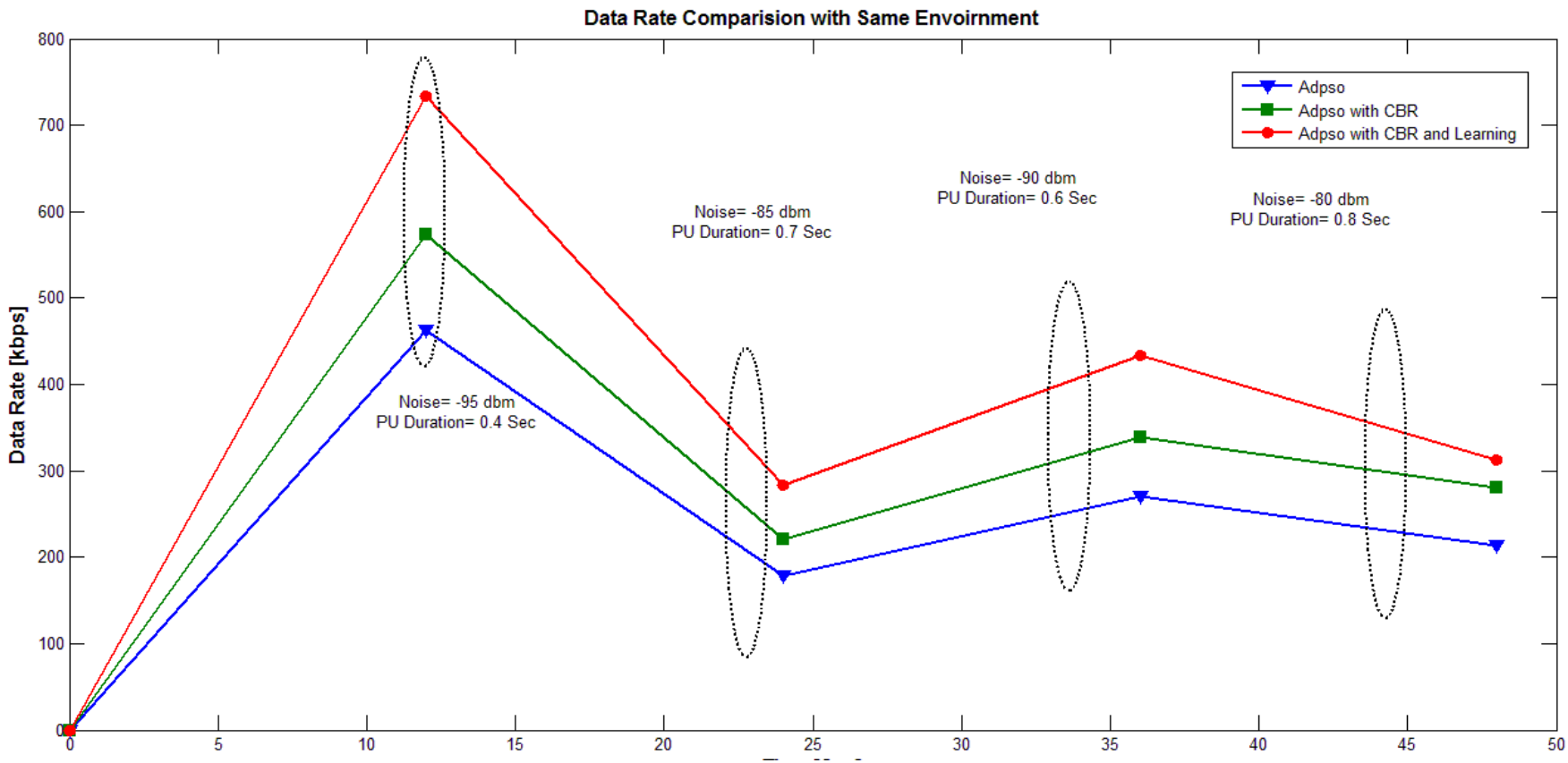
Evaluation: Fitness value



Evaluation: Data Rate



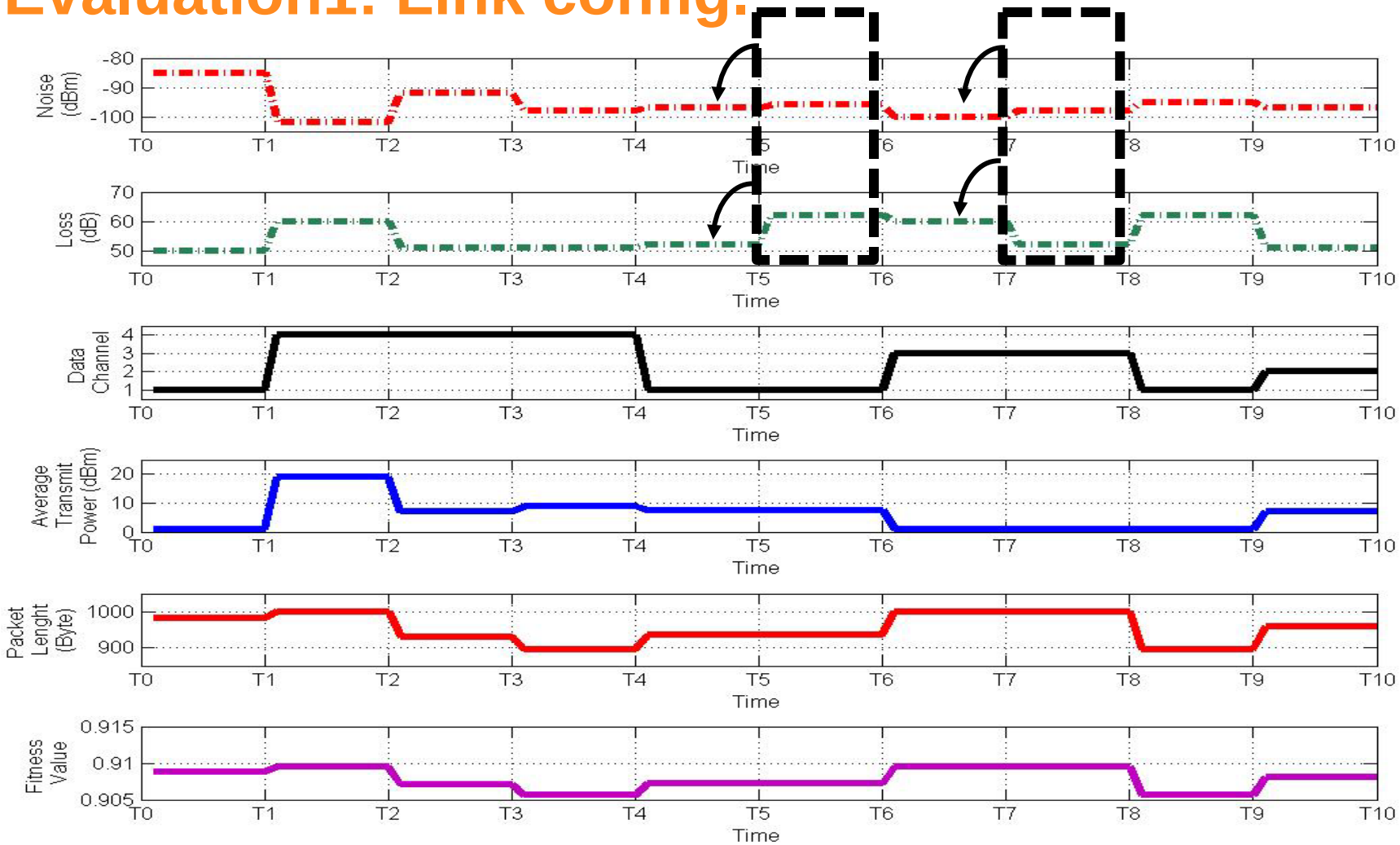
State of the Art

- Genetic Algorithm (GA) for link adaptation [1]
  - Only for static environment
  - No PU activities model
- Energy-efficient packet size optimization[2]
  - Fixed packet size – redundant retransmissions
  - Only for static environment
- Adaptive Discrete Particle Swarm Optimization (ADPSO)
  - Algorithm run for every environmental change
  - New configuration for every packet

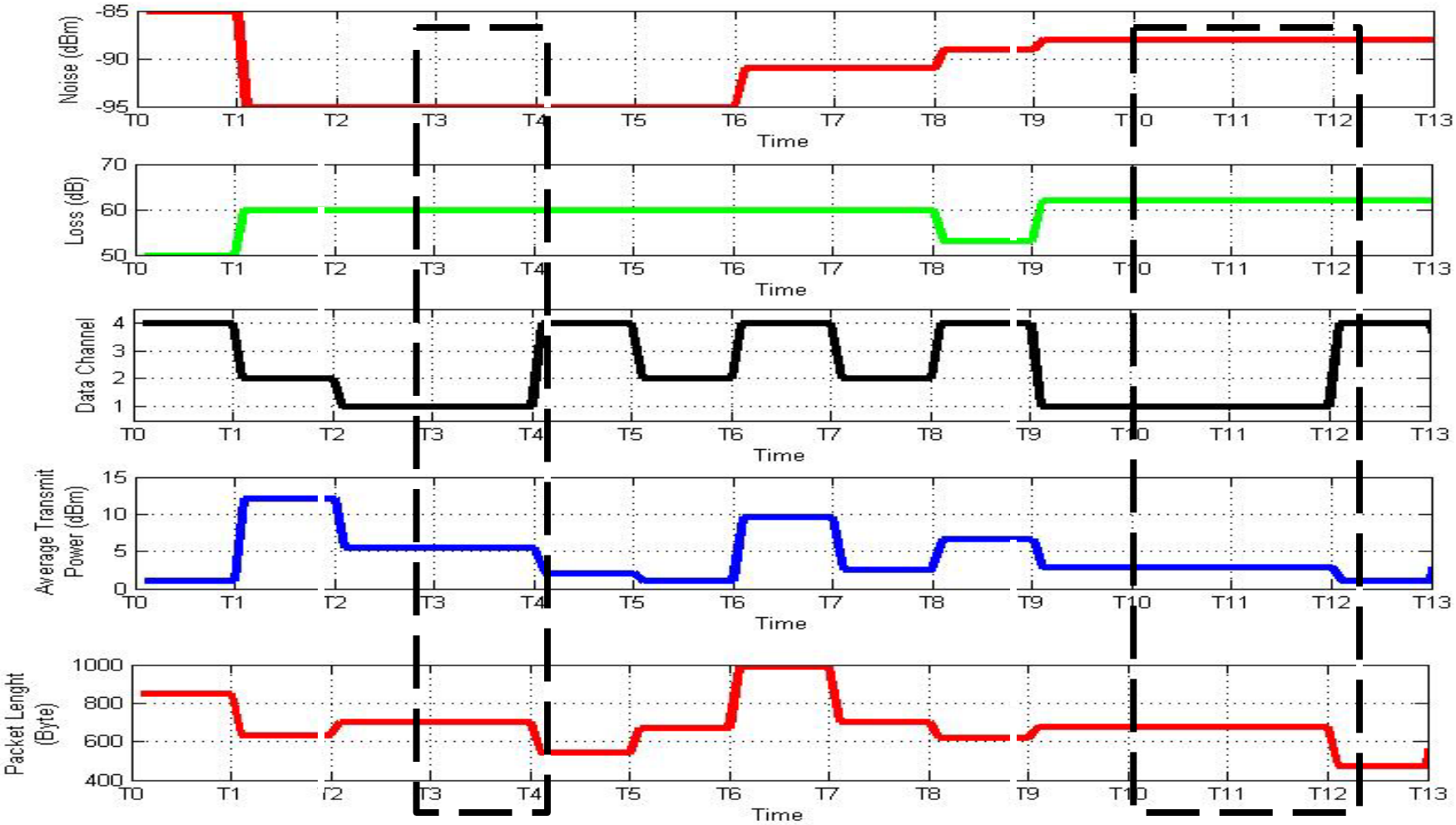
→ **Need to new approach**

[1] T. R. Newman, B. A. Barker, A. M. Wyglinski, A. Agah, J. B. Evans, and G. J. Minden, "Cognitive engine implementation for wireless multicarrier transceivers," *Wireless Communications and Mobile Computing*, vol. 7, no. 9, pp. 1129–1142, November 2007.
[2] M. Oto and O. Akan, "Energy-efficient packet size optimization for cognitive radio sensor networks," *IEEE Transactions on Wireless Communications*, vol. 11, no. 4, pp. 1544–553, April 2012.

Evaluation1: Link config.



Evaluation1: Link configuration



Time plan

April 2013 – September 2013

- Q-L in CE
- Simulate CE in OMNeT++
- Poster at Sophia Antipolis
- Publications: 1 accepted 2 planned to submit
- Practical implementation (**in progress**)

October 2013 – May 2014

- Practical implementation
- Writing dissertation

Scenarios

- Objectives [1,2]
  - High Throughput $$fThr_{max} = \frac{\frac{L}{L+O}(1-BER)^{L+O} R_b}{\frac{L_{max}}{L_{max}+O} R_{bmax}}$$
  - Low Transmission delay $$fdelay_{min} = \left(\frac{\frac{1}{R_{b\,max}} L_{min}}{\frac{1}{R_b} L} \right)$$

Similarity

- Input:
  - Noise → Normalization → Norm(N)
  - Loss → Normalization → Norm(L)
- Previous states:
  - $Noise_{-t}$ → Normalization → $Norm(N_{-t})$
  - $Loss_{-t}$ → Normalization → $Norm(L_{-t})$
- Euclidean Distance (ED)

$$= \sqrt{(Norm(N) - Norm(N_{-t}))^2 + (Norm(L) - Norm(L_{-t})^2}$$

- Similarity

$$= 1 - ED$$

PU activities model

- Generate exponential random variables[2]
  - IDLE N_i
  - BUSY N_b
- Mean of the exponential random variables
  - $n_i = mean(N_i)$
  - $n_b = mean(N_b)$
- Probability of PU state:
  - Probability of IDLE
    - $Pr_{idle} = \frac{n_i}{n_i + n_b}$
  - Probability of BUSY
    - $Pr_{busy} = \frac{n_b}{n_i + n_b}$

[2] M. Oto and O. Akan, "Energy-efficient packet size optimization for cognitive radio sensor networks," *IEEE Transactions on Wireless Communications*, vol. 11, no. 4, pp. 1544–553, April 2012.

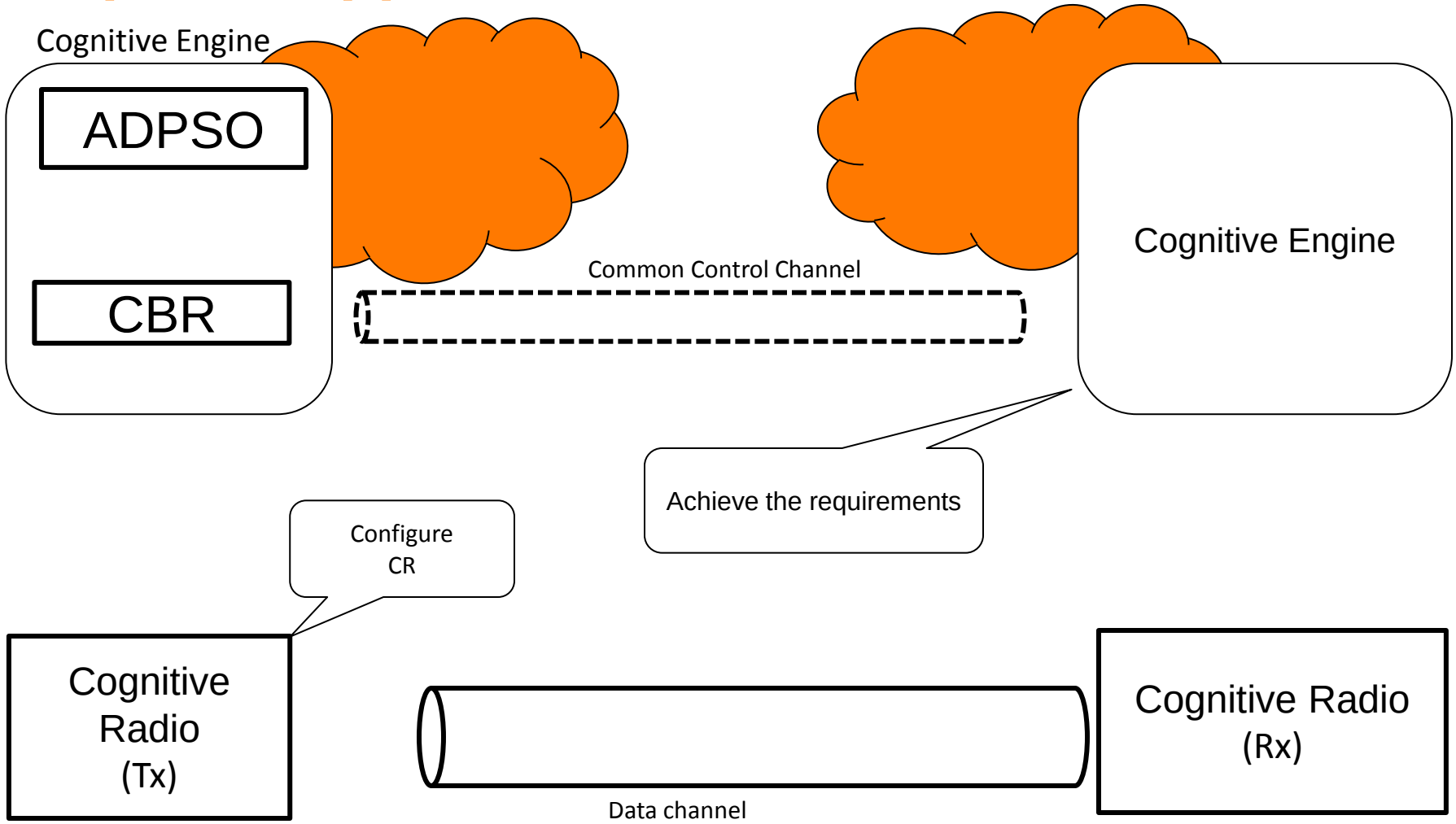
Proposed approach (cont.)

- Rx sends to Tx over CCC
  - ACK/ NACK according to PER
  - Rx sends current environmental factors (Noise, Loss)
  - Current free channels

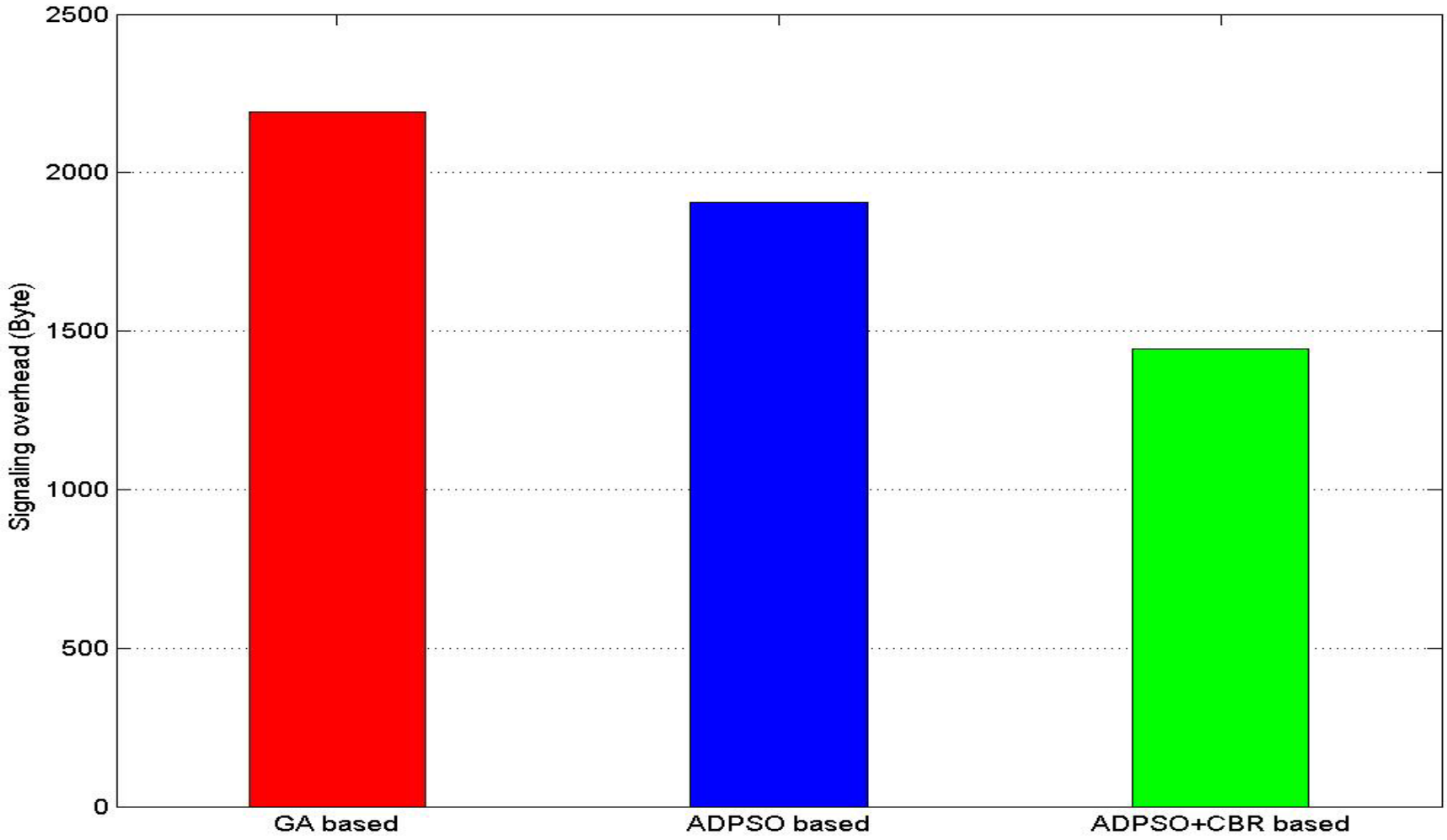
Frame control	Duration ID	RA	ACK/NACK	Noise	Loss	Free channels	FCS

CCC:Common Control Channel

Proposed approach



Evaluation 2: Signaling overhead



Conclusion

- Efficient approach in time and signaling overhead for dynamic environment
- Works under different scenarios
- Achievements:
  - Dynamic link configuration
  - High convergence values (Fitness values)
  - Low time
  - Low signaling overhead

Simulation

Parameter	Value
Transmit power (dBm)	0 - 25
Modulation scheme	PSK
Modulation index	0, 1, 2, 3, 4
Packet length (Byte)	100 - 1000
Code rate	1/2 - 7/8
Channel type	AWGN
No. of Free channels	16
Bandwidth of channel	50 kHz
Noise (dBm)	-85
Path loss (dB)	90

Scenario	R_b(kbps)	BER
Voice	64	10^{-3}
Video	500	10^{-4}
Data	300	10^{-6}

Weights	M_1	M_2	M_3
w_1	0.1	0.1	0.8
w_2	0.1	0.1	0.1
w_3	0.1	0.1	0.1
w_4	0.7	0.7	0

$$f_{total} = w_1 f_{Thr} + w_2 f_{power} + w_3 f_{BER} + w_4 f_{delay}$$

Weights and QoS requirements

Weights	Voice	Video	Data
w_1	0.1	0.1	0.8
w_2	0.1	0.1	0.1
w_3	0.1	0.1	0.1
w_4	0.7	0.7	0

Link's objectives:

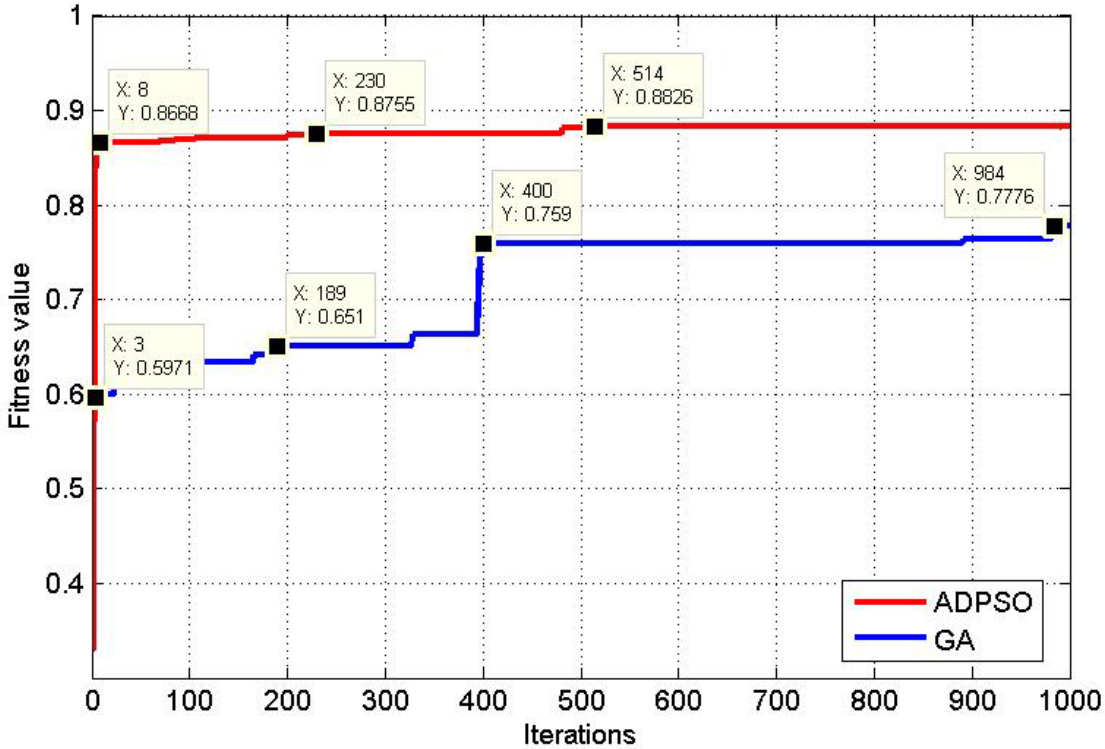
- High throughput (f_1)
- Low transmission delay (f_2)
- Low BER (f_3)
- Low power consumption (f_4)

Total fitness:

- $f_{total} = \sum_{i=1}^{4} w_i f_i$

Scenario	R_b(kbps)	BER
Voice	64	10^{-3}
Video	500	10^{-4}
Data	300	10^{-6}

Results: Convergence in voice scenario



Weights	W_1	W_2	W_3	W_4
Voice	0.1	0.7	0.1	0.1

Weights and GA model are in [2]