Comparison of contention-based protocols for secondary access in TV whitespaces

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Outline

- We compare performance of protocols 802.11 and ECMA-392
- Backoff behaviour of both protocols is evaluated using Markov chains
- Fast and efficient way to solve these large and complex chains
- Adjusting a single parameter means a high throughput can be maintained over a range of system sizes
- Suitable for TV whitespace use

Bianchi 2000 — the classic paper

- Performance Analysis of the IEEE 802.11 Distributed Coordination Function. *IEEE Journal on selected areas in communications*, vol. 18, (March 2000), pp. 535–547.

Bianchi 2000 variables

p	Collision probability
τ	Transmission probability for a single station
n	Number of terminals in the network
S	System throughput
P_{s}	Probability of any particular transmission being successful
P_{tr}	Probability of a transmission occurring in a particular timeslot
$E[P]$	Average payload packet size
T_{s}	Time for a successful frame exchange sequence
T_{c}	Time for an unsuccessful (collision) frame exchange sequence

Bianchi 2000 throughput calculation

$$\begin{aligned}
S &= \frac{P_{\mathsf{s}} P_{tr} E[P]}{(1-P_{\mathsf{tr}})\sigma + P_{\mathsf{tr}} P_{\mathsf{s}} T_{\mathsf{s}} + P_{\mathsf{tr}}(1-P_{\mathsf{s}} T_{\mathsf{c}})} \\
p &= 1-(1-\tau)^{n-1} \\
P_{\mathsf{tr}} &= 1-(1-\tau)^{n} \\
P_{\mathsf{s}} &= \frac{n\tau(1-\tau)^{n-1}}{1-(1-\tau)^{n}}
\end{aligned}$$

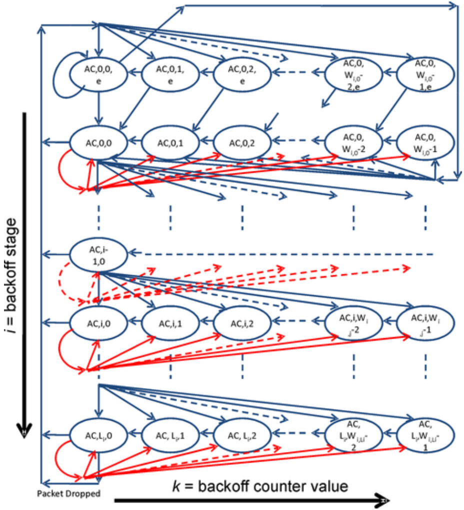
Bianchi 2000 Markov Chain

```
ProbabilityMatrix Bianchi(int w0, int m, double p) { // Bianchi eqn 1
  int i,k,w=w0;
  double a=(1.0-p)/w0,b;
  ProbabilityMatrix P;
  for (i=0; i<=m; i++) {
    b=p/w;
    for (k=0; k<w; k++) {
      if (k<w-1) P.add_element(Tuple(i,k+1),Tuple(i,k),1.0);
      if (k<w0)  P.add_element(Tuple(i,0  ),Tuple(0,k),a);
      if (i)     P.add_element(Tuple(i-1,0),Tuple(i,k),b);
      if (i==m)  P.add_element(Tuple(i,0  ),Tuple(i,k),b);
    }
    w*=2;
  }
  return P;
}
```

Mathematical solution methods

- *transition matrix* P: P_{ij} is the probability of moving to state j given that we are in state i
- Solve $z^{\mathsf{T}}(I-P)=0$ for equilibrium vector z with $||z||=1$
- This is a numerical solution of a very large sparse linear system
- Nonlinear equation solver to find τ (hence P_{tr}) iteratively
- Thus tells us the fraction of time the system spends in each state
- Final output: throughput performance as a function of design parameters and system load

ECMA-392 PCA protocol

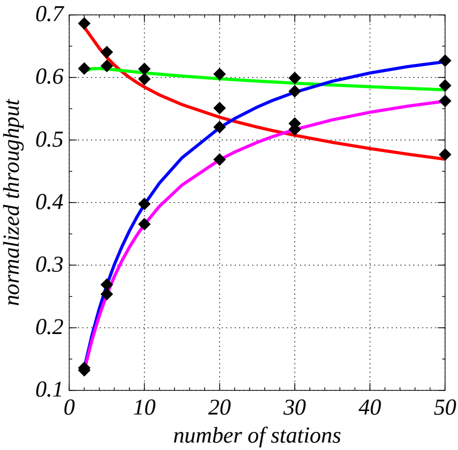


Markov chain to compare the backoff behaviour of the 802.11 EDCA and ECMA-392 PCA (red and blue) protocols. In ECMA, CW is only reset after a successful transmission when the queue is empty, in an attempt to avoid congestion

ECMA Markov chain defined

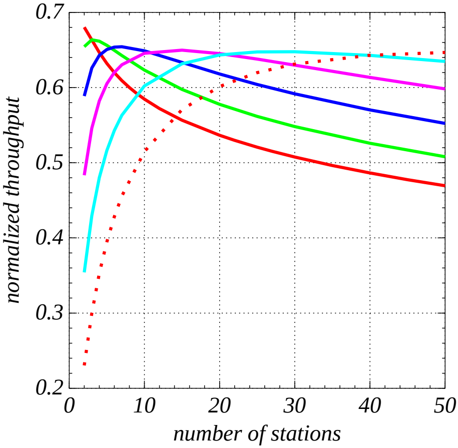
```
ProbabilityMatrix ECMA(int w0, int m, double p) { // ECMA eqn 1
  int i,k,w=w0;
  double b,c;
  ProbabilityMatrix P;
  for (i=0; i<=m; i++) {
    b=p/w; c=(1.0-p)/w;
    for (k=0; k<w; k++) {
      if (k<w-1) P.add_element(Tuple(i,k+1),Tuple(i,k),1);
      if (1)     P.add_element(Tuple(i,0  ),Tuple(i,k),c);
      if (i)     P.add_element(Tuple(i-1,0),Tuple(i,k),b);
      if (i==m)  P.add_element(Tuple(i,0  ),Tuple(i,k),b);
    }
    w*=2;
  }
  return P;
}
```

Results — system capacity



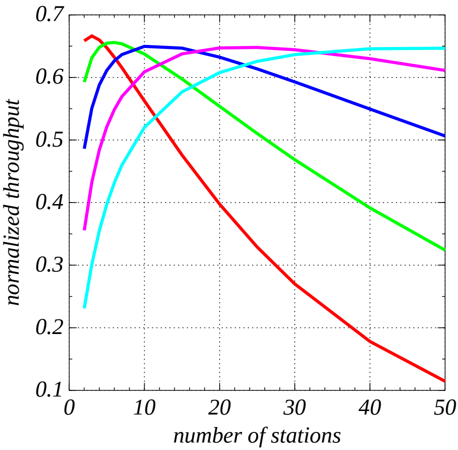
802.11 EDCA-type system (basic, RTS). ECMA-392 PCA-type system (basic, RTS). Black=simulation.

Adjusting 802.11



Adjusting 802.11
EDCA-type system
CW_{min} to maintain
high throughput.
$CW_{\text{min}} = 15, 31, 63, 127, 255, 511.$

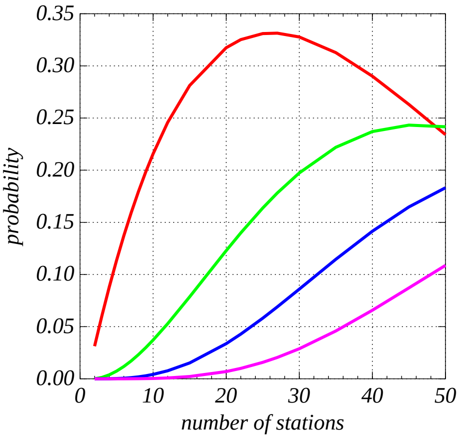
Adjusting ECMA-392



Adjusting ECMA-392 system CW_{min} to maintain high throughput.

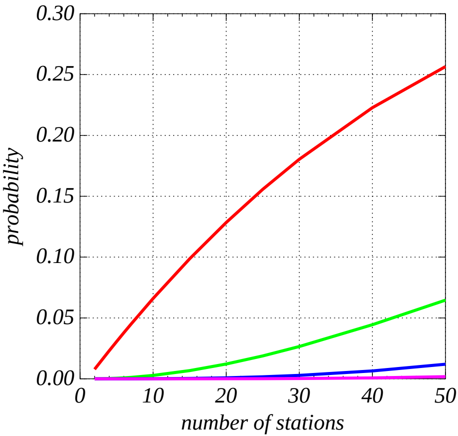
$CW_{\text{min}} = 31, 63, 127, 255, 511$.

Collision behaviour of ECMA-392



Collision behaviour of ECMA-392 for CW_{min} =7 and CW_{max} =31. Pr$[NTX{=}2]$, Pr$[NTX{=}3]$, Pr$[NTX{=}4]$, Pr$[NTX{=}5]$.

Collision behaviour of ECMA-392



Collision behaviour of ECMA-392 for CW_{min} =7 and CW_{max} =127.
Pr$[NTX{=}2]$,
Pr$[NTX{=}3]$,
Pr$[NTX{=}4]$,
Pr$[NTX{=}5]$.

Summary

- Using the same parameters, 802.11-type systems achieve higher throughput for small networks
- ECMA-392 type systems offer better coexistence with other secondary systems using the same channel and better throughput performance for networks with many terminals
- By adjusting one parameter CW_{min}, a high thoughput can be maintained over a wide range of network sizes
- When using parameters which maintain a high throughput, the collision probability is kept low; when there is a collision it is unlikely to involve more than two simultaneous transmissions
- This limits aggregate interference where the secondary systems might interfere with the channels primary users
- More details on QoSMOS project: `http://www.ict-qosmos.eu`