Real-Time in Sweden 2003

On Real-Time Control with Limited Feedback Communication

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RECSYS
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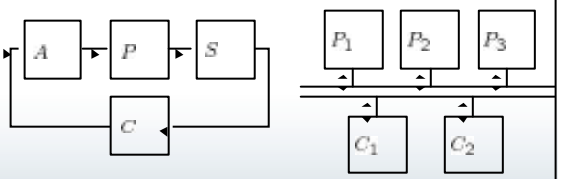
From Traditional Control to Network Embedded Control



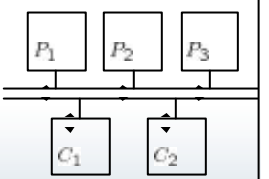
Control under novel uncertainties and constraints
- Shared communication and computation resources
- Network traffic congestions
- Quantization effects
- Limited communication bandwidth

Motivating Network Control Applications

Research Agenda at S3-KTH in Network Embedded Control

- Control under limited communication
- Integrated coding and control
- Control of network traffic

- Applications in automobiles, internetworking, multi-robot systems, wireless communication



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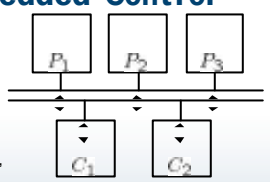
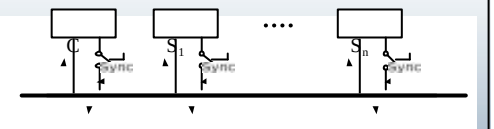


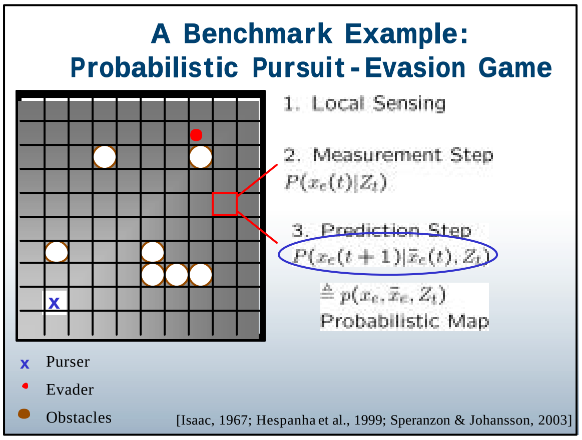
Examples to discuss here:

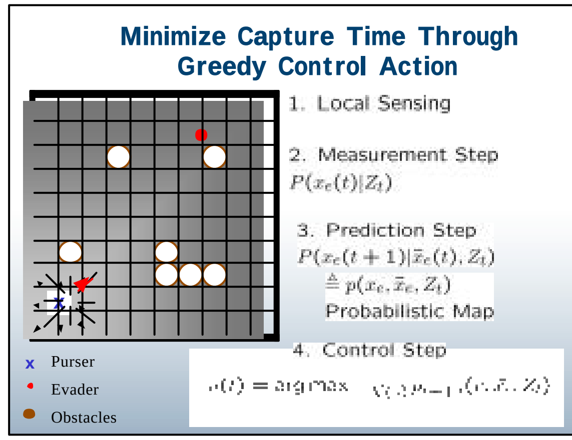
1. Smart sensors
2. Adaptive quantization
3. Controls in wireless TCP

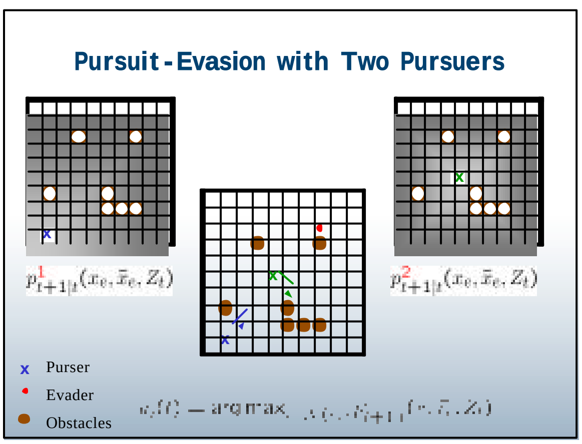
Smart Sensing

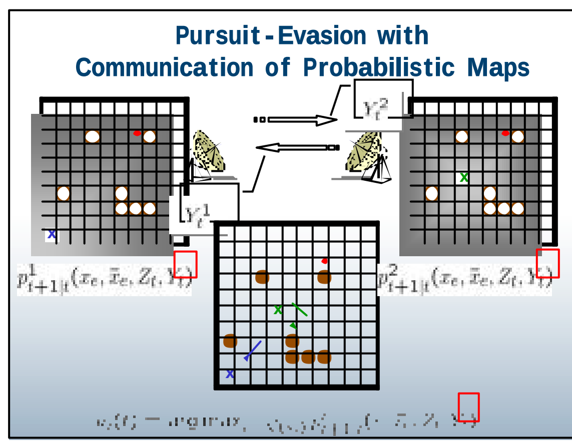
- Minimize sensor communication to reduce traffic congestion and power consumption
- How can a sensor know that it has useful info?
- Analyze data by information theoretic measures

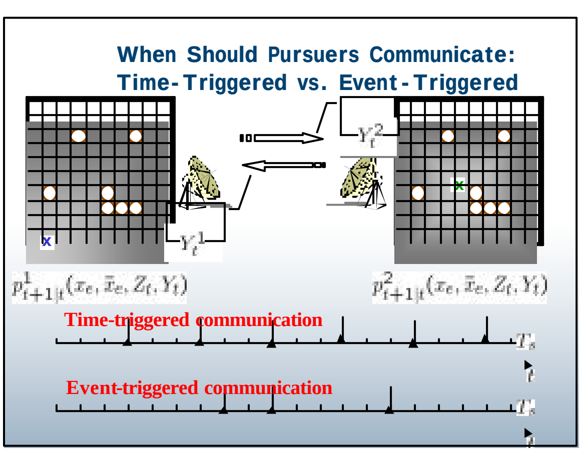


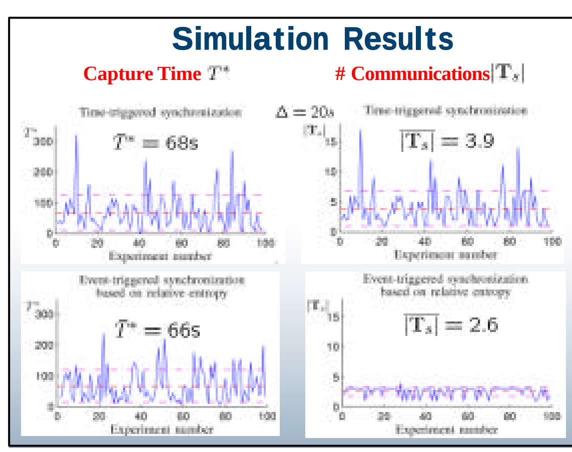

A Benchmark Example:
Probabilistic Pursuit-Evasion Game
1. Local Sensing
2. Measurement Step
$P(x_e(t)|Z_t)$
3. Prediction Step
$P(x_e(t+1)|\bar{x}_e(t), Z_t)$
$\triangleq p(x_e, \bar{x}_e, Z_t)$
Probabilistic Map
Purser
Evader
Obstacles
[Isaac, 1967; Hespanha et al., 1999; Speranzon & Johansson, 2003]


Minimize Capture Time Through
Greedy Control Action
1. Local Sensing
2. Measurement Step
$P(x_e(t)|Z_t)$
3. Prediction Step
$P(x_e(t+1)|\bar{x}_e(t), Z_t)$
$\triangleq p(x_e, \bar{x}_e, Z_t)$
Probabilistic Map
4. Control Step
Purser
Evader
Obstacles

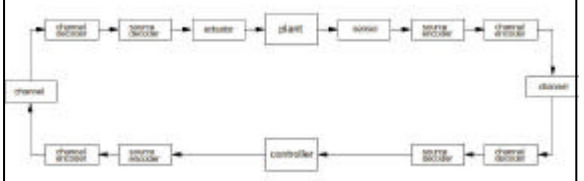

Pursuit-Evasion with Two Pursuers
$p^1_{t+1|t}(x_e, \bar{x}_e, Z_t)$
$p^2_{t+1|t}(x_e, \bar{x}_e, Z_t)$
Purser
Evader
Obstacles


Pursuit-Evasion with
Communication of Probabilistic Maps
Y^2_t
Y^1_t
$p^1_{t+1|t}(x_e, \bar{x}_e, Z_t, Y_t)$
$p^2_{t+1|t}(x_e, \bar{x}_e, Z_t, Y_t)$


When Should Pursuers Communicate:
Time-Triggered vs. Event-Triggered
Y^2_t
Y^1_t
$p^1_{t+1|t}(x_e, \bar{x}_e, Z_t, Y_t)$
$p^2_{t+1|t}(x_e, \bar{x}_e, Z_t, Y_t)$
Time-triggered communication
Event-triggered communication
T_s
t


Simulation Results
Capture Time T^*
Communications $|T_s|$
$\Delta = 20s$
Time-triggered synchronization
$T^* = 68s$
$|T_s| = 3.9$
Event-triggered synchronization based on relative entropy
$T^* = 66s$
$|T_s| = 2.6$
Experiment number

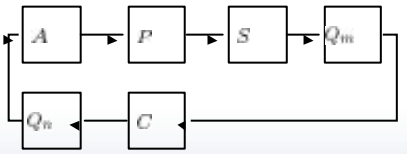
Integrated Coding and Control



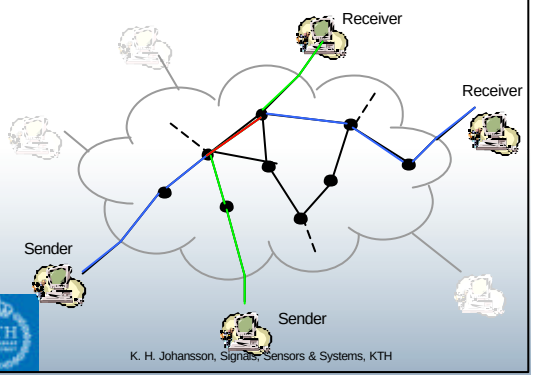
- All blocks influence control performance
- Joint design of channel/source codes and control
- Quantization

[Bao, Johansson, Skoglund, 2003]

Quantized Control System

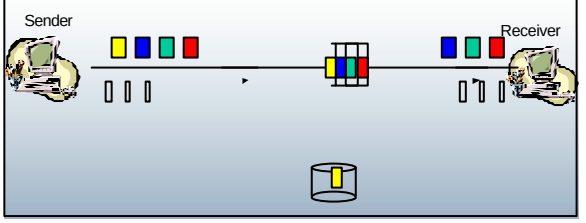


Congestion in Data Network

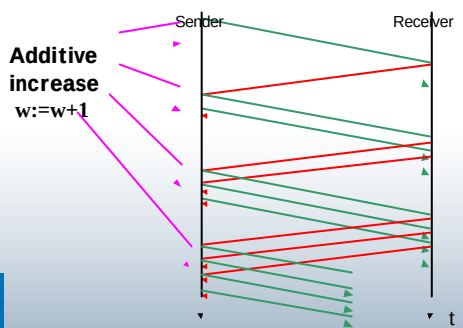


Congestion in Bottleneck Link

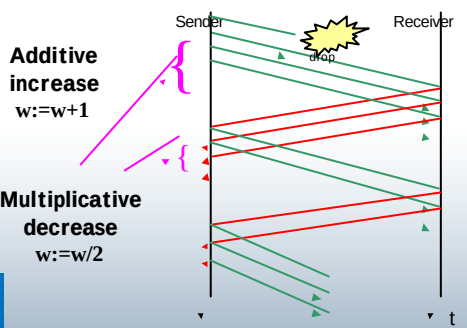
- Temporary storage of data in router queues
- Sender receives data acknowledgments from receiver
- Sending rate controlled to maximize utilization of link through transmission control protocol (TCP)



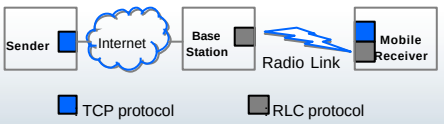
Transmission Control Protocol



Transmission Control Protocol

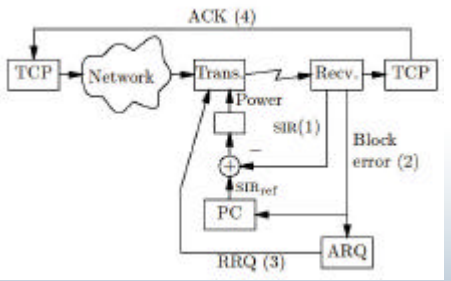


Mobile Internet Architecture



TCP protocol RLC protocol

Wireless TCP



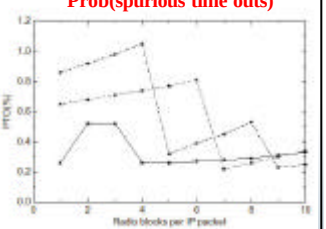
[Möller & Johansson, 2003]

Wireless TCP

IP packet delay distribution

n	$\Delta = 0.2$	$\Delta = 0.06$	$\Delta = 0.02$
1	0.31±0.94	0.32±0.99	0.33±1.03
2	0.51±1.08	0.53±1.15	0.54±1.20
3	0.62±1.08	0.64±1.18	0.65±1.24
4	0.72±1.09	0.74±1.21	0.76±1.28
5	0.83±1.09	0.85±1.23	0.87±1.31
6	0.94±1.09	0.96±1.25	0.98±1.35
7	1.06±1.09	1.07±1.27	1.09±1.38
8	1.17±1.09	1.18±1.29	1.19±1.41
9	1.28±1.09	1.29±1.30	1.30±1.44
10	1.39±1.09	1.40±1.31	1.41±1.46

Prob(spurious time outs)



Performance degradation up to 16%!

[Möller & Johansson, 2003]

Summary

- Network embedded control of growing importance
- Control with non-traditional uncertainties and constraints

Brief discussion on ongoing work:

- Control under limited communication
- Control with adaptive quantization levels
- Control in wireless Internet

http://www.s3.kth.se/~kallej