# Simultaneous Operation of Multiple Collocated Radios and the Scanning Problem

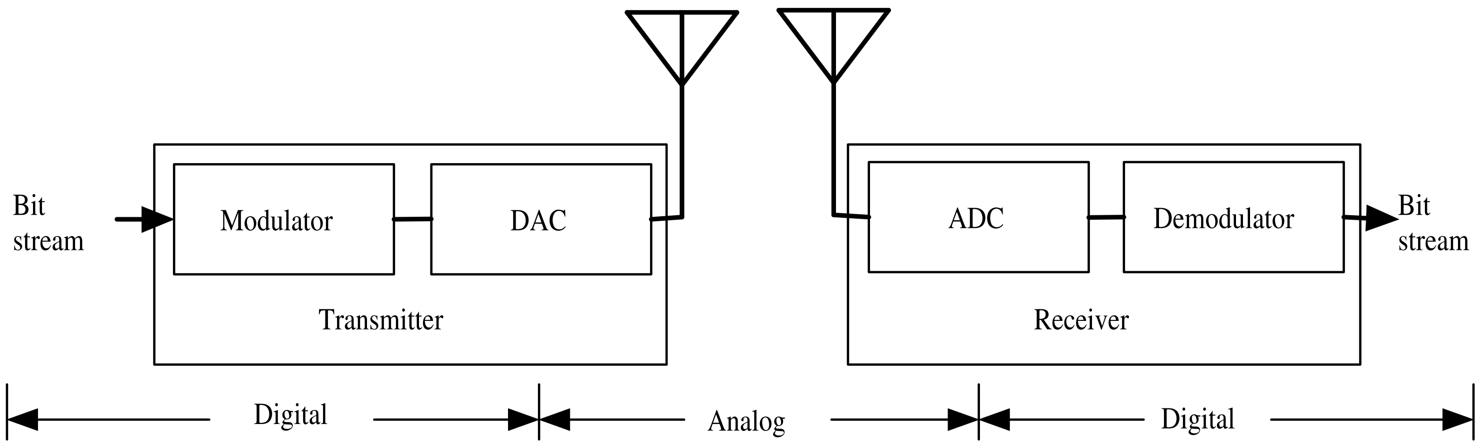
Michel Barbeau
Université Carleton University

August 20, 2011

# Outline

- Software Defined Radio
- Multiple collocated radio operation
- Scanning strategies

# Overall architecture of a Software Defined Radio*




*See: Barbeau and Kranakis, *Principles of Ad Hoc Networking, Chapter 1*.

# Multiple collocated radio operation

- A device capable of operating *at the same time* several modes and frequencies, e.g. 802.11 and 802.16. Each is called a radio.*

- Radios share resources partially (e.g. antenna) or entirely (e.g. software defined radio).

- Interference and hardware conflicts? Scheduling is required! Turn-based model!†

*See: Zhu and Yin, *Enabling collocated coexistence in IEEE 802.16 networks via perceived concurrency*, 2009.

†Zhu and Markovits, Techniques for detecting beacons on wireless channels - US Patent Application, 2010.

# Probabilistic models of scanning strategies

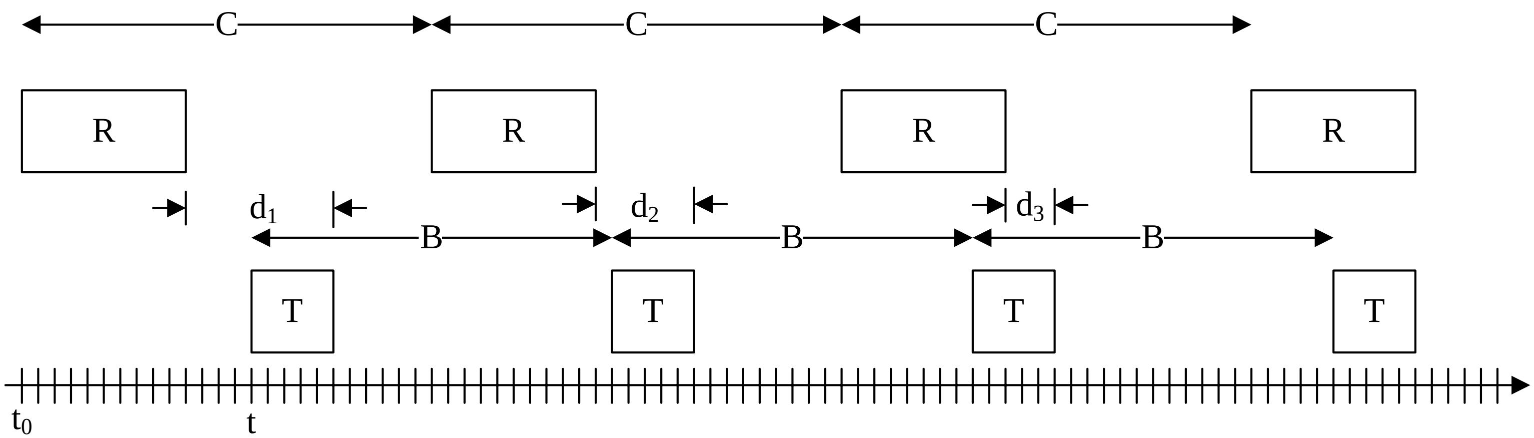
1. Sequential

2. <u>Sliding-window</u>

3. Pseudo-concurrent

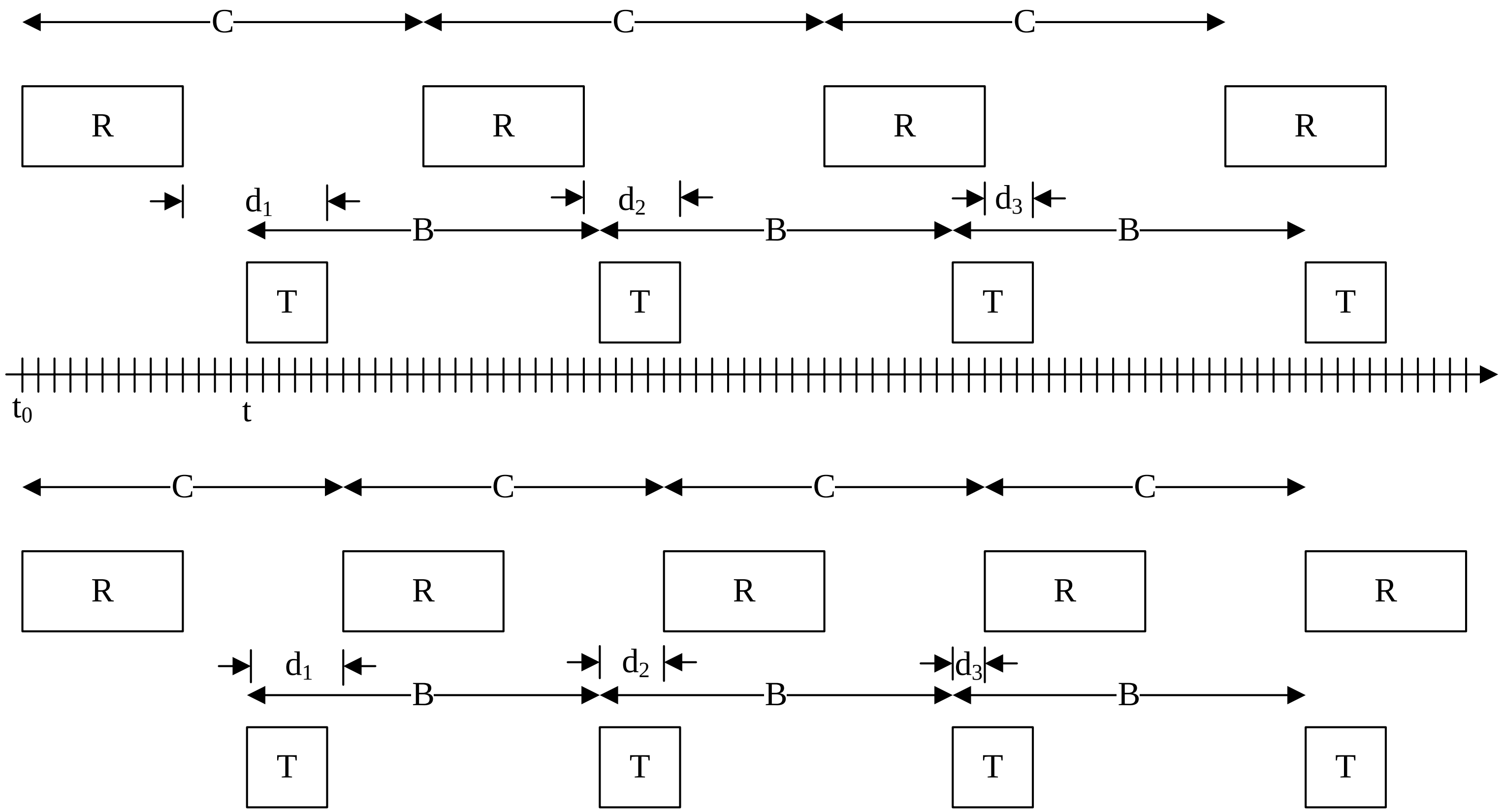
4. <u>Truly-concurrent</u>

# Sequential scanning*: $C > B$




*Model of Zhu and Markovits.

# Sequential scanning*: $C > B$ or $C < B$




*Model of Zhu and Markovits.

# Probabilistic model of sequential scanning

Number of cycles until beacon transmission $T$ falls within receive window $R$, as a function of $t \in 0 \ldots B$:

$$k_t = \begin{cases} \left\lceil \frac{t+T-R}{C-B} \right\rceil + 1 & : \quad C > B \\ 1 + (R - T < t < C) \cdot \left\lceil \frac{C-t}{B-C} \right\rceil + (C \leq t) & : \quad C < B \end{cases}$$

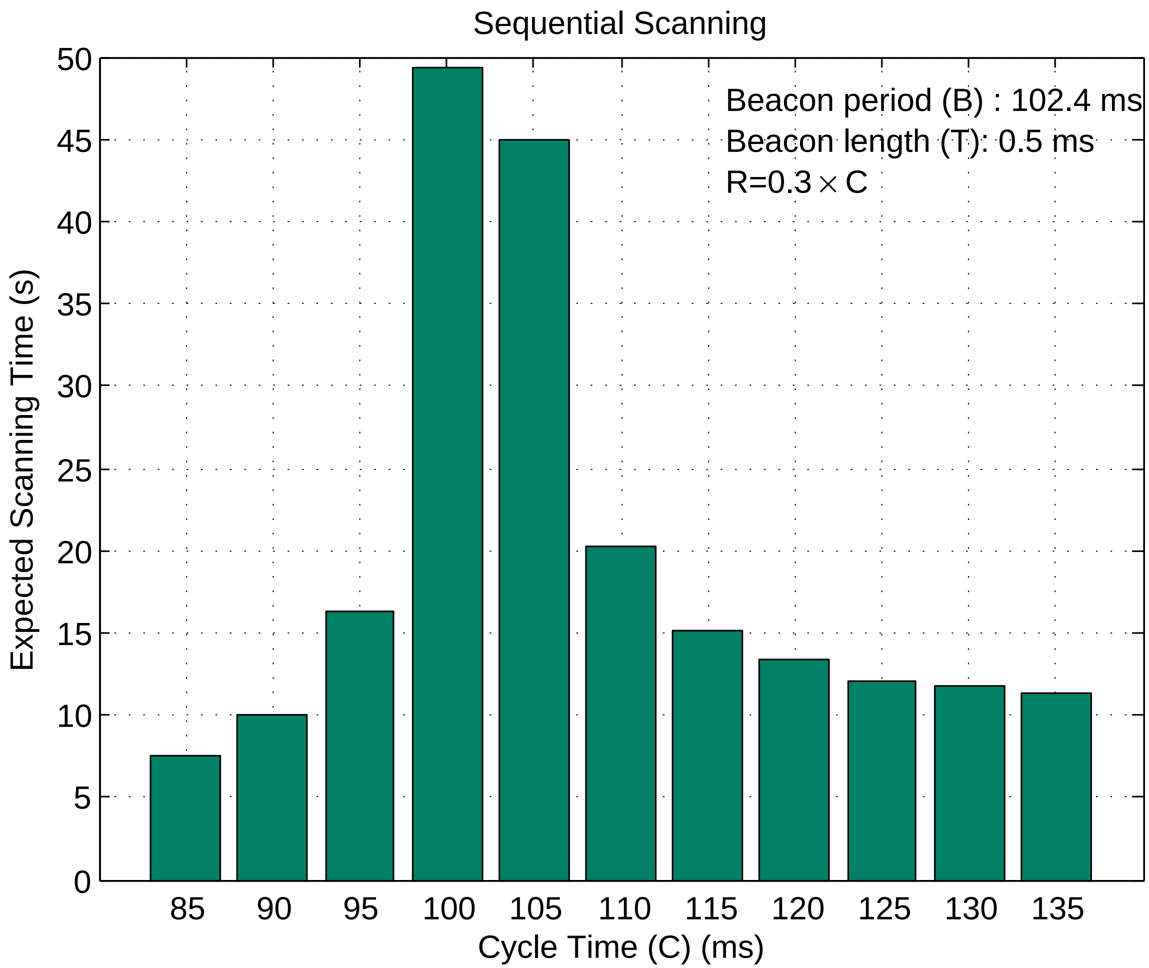
Assuming $t$ follows a uniform distribution, expectation of number of cycles $k \in k_0 \ldots k_B$:

$$E[k] = \frac{\sum_t k_t}{B}$$

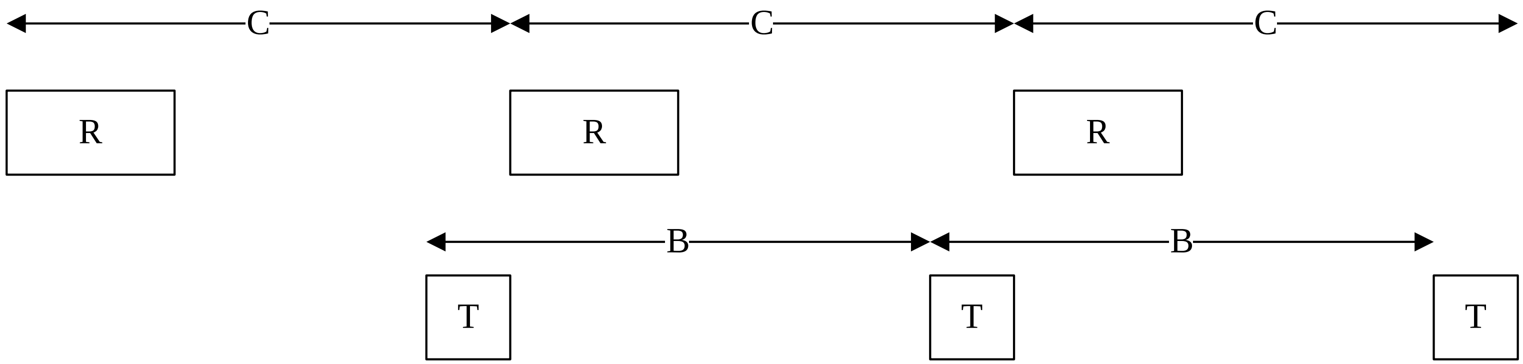
Given $n$ channels to scan, expectation of sequential scanning time $S$:

$$E[S] = n \cdot C \cdot E[k]$$

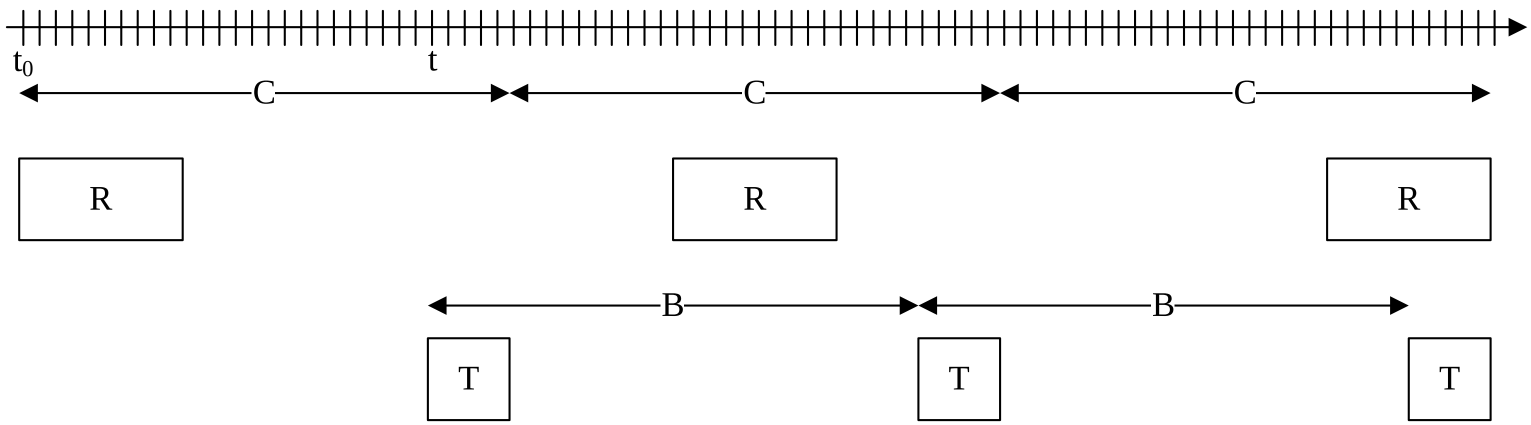
# Sequential scanning: $C > B$ or $C < B$



$$C = B$$



# Sliding-window scanning: $C = B$



# Probabilistic model of sliding-window scan.: $C = B$

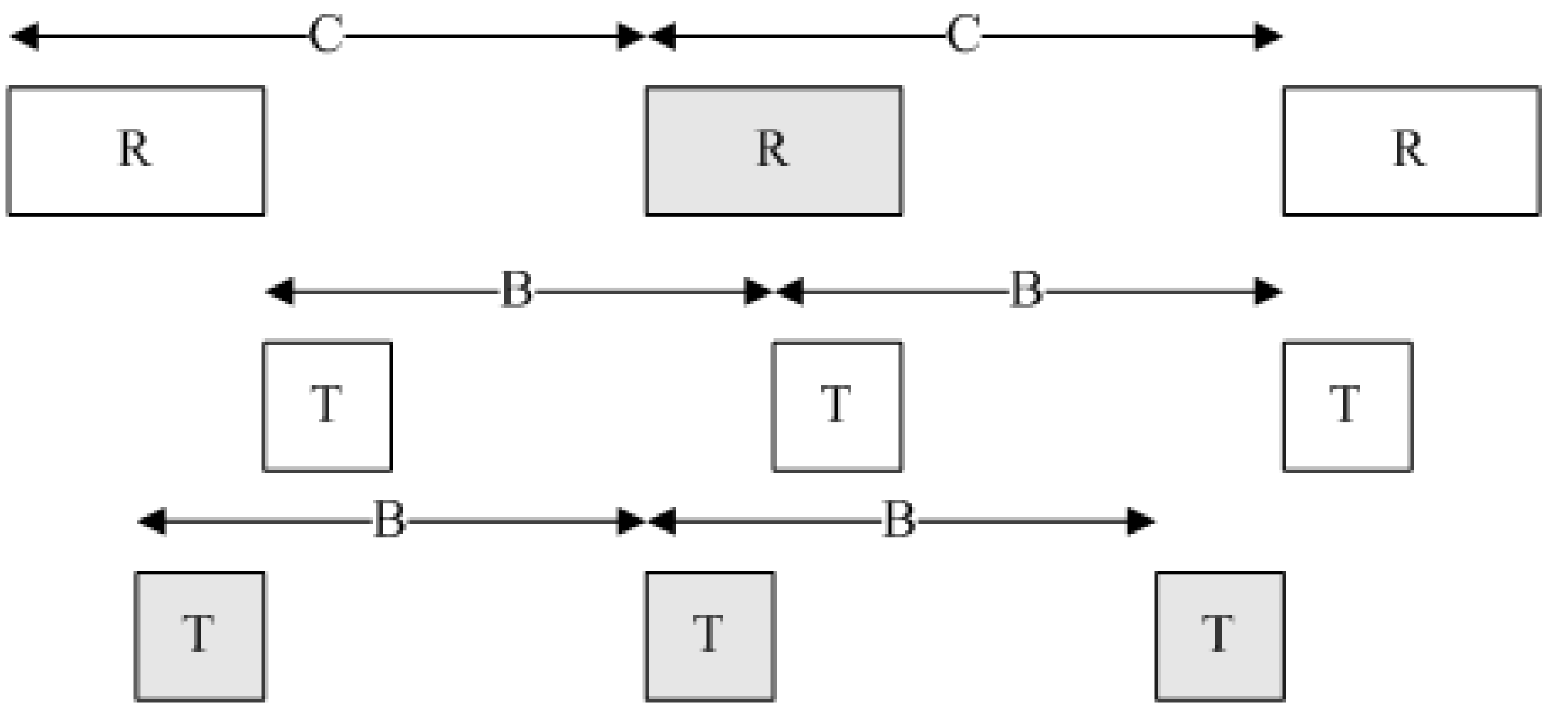
Number of cycles until beacon transmission $T$ falls within receive window $R$, as a function of $t \in 0 \ldots B$:

$$k_t = \left\lceil \frac{t}{R - T} \right\rceil$$

Expectation of $k$:

$$E[k_t] = \frac{1}{B} \sum_{t=0}^{B} k_t$$

# Pseudo-concurrent scanning: $C > B$ or $C < B$



# Prob. model of pseudo-concurrent scanning: $C \neq B$

Group size: $m = \left\lfloor \frac{R}{|C-B|} \right\rfloor$

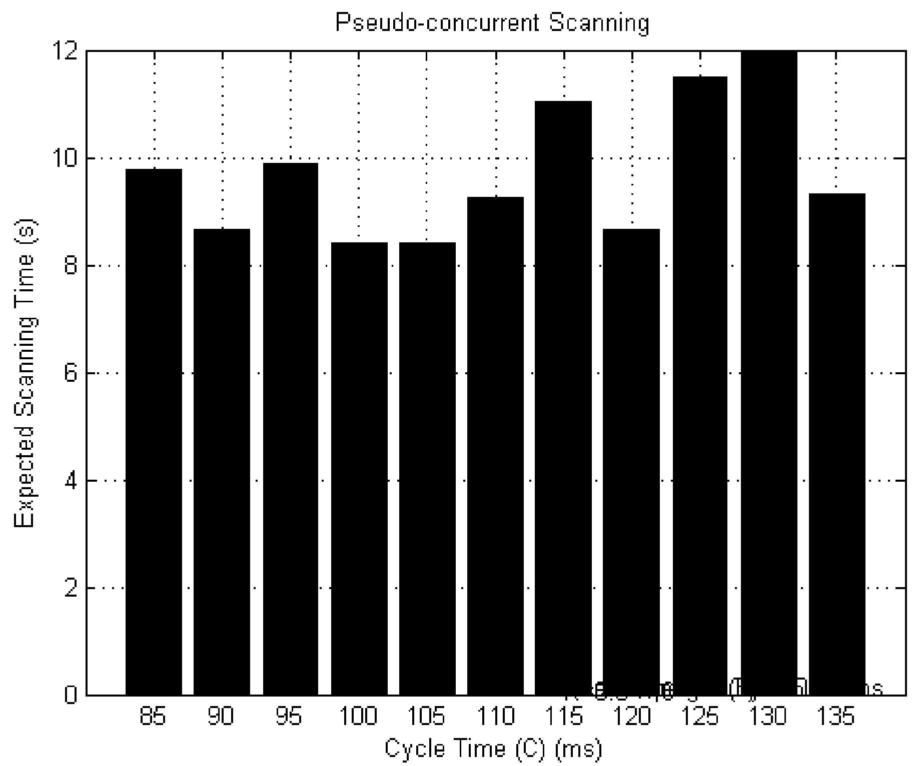
Number of cycles per group, function of $t \in 0 \ldots B + (m-1) \cdot T$:

$$k \leq \begin{cases} \left\lceil \frac{B+T-R}{C-B} \right\rceil + m & : \quad C > B \\ & : \\ \left\lceil \frac{C+T-R}{B-C} \right\rceil + m & : \quad C < B \end{cases}$$

Worst case scanning time:

$$\left\lceil \frac{n}{m} \right\rceil \cdot C \cdot k$$

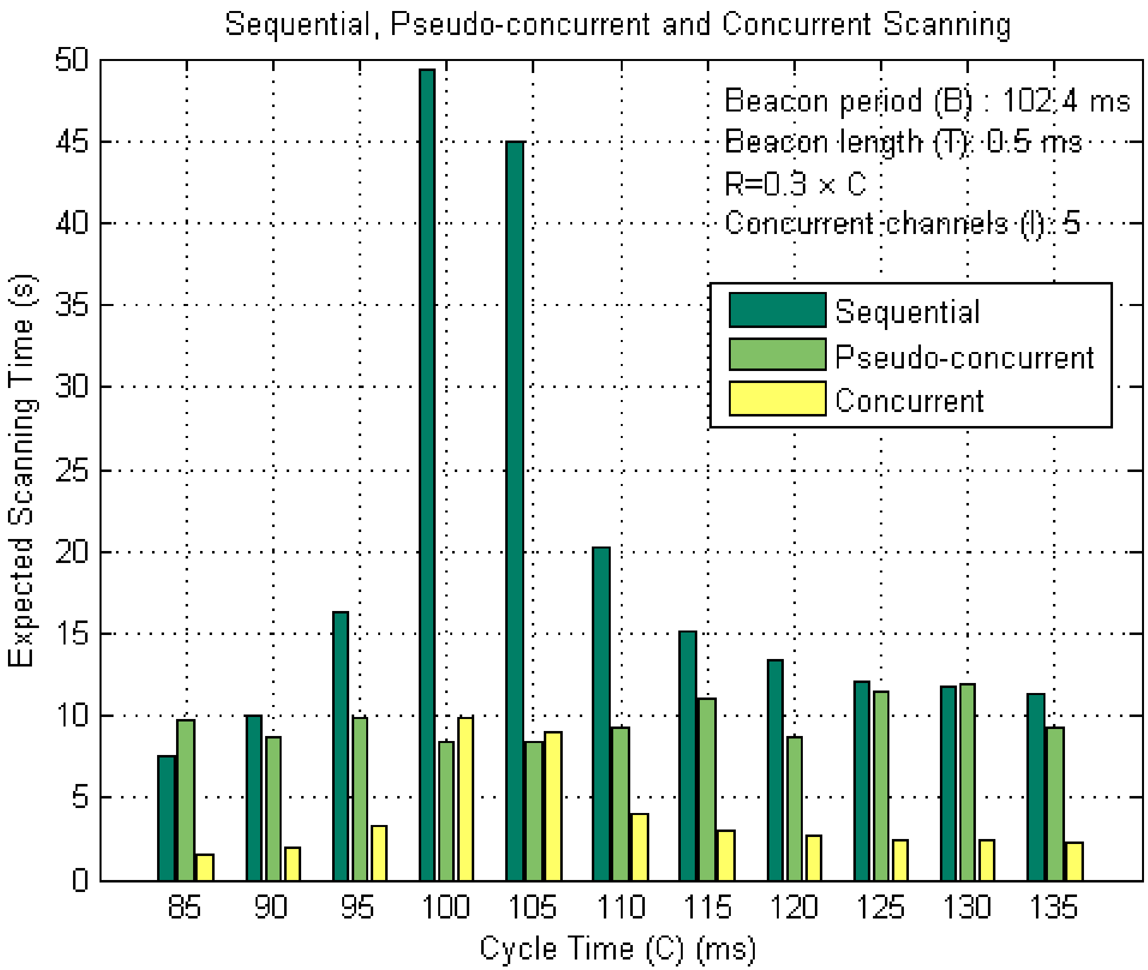
# Pseudo-concurrent scanning: $C > B$ or $C < B$



# Truly-concurrent scanning

With $l$ concurrently scanned channels, scanning time $S$:

$$E[S] \leq \left\lceil \frac{n}{l} \right\rceil \cdot C \cdot k$$

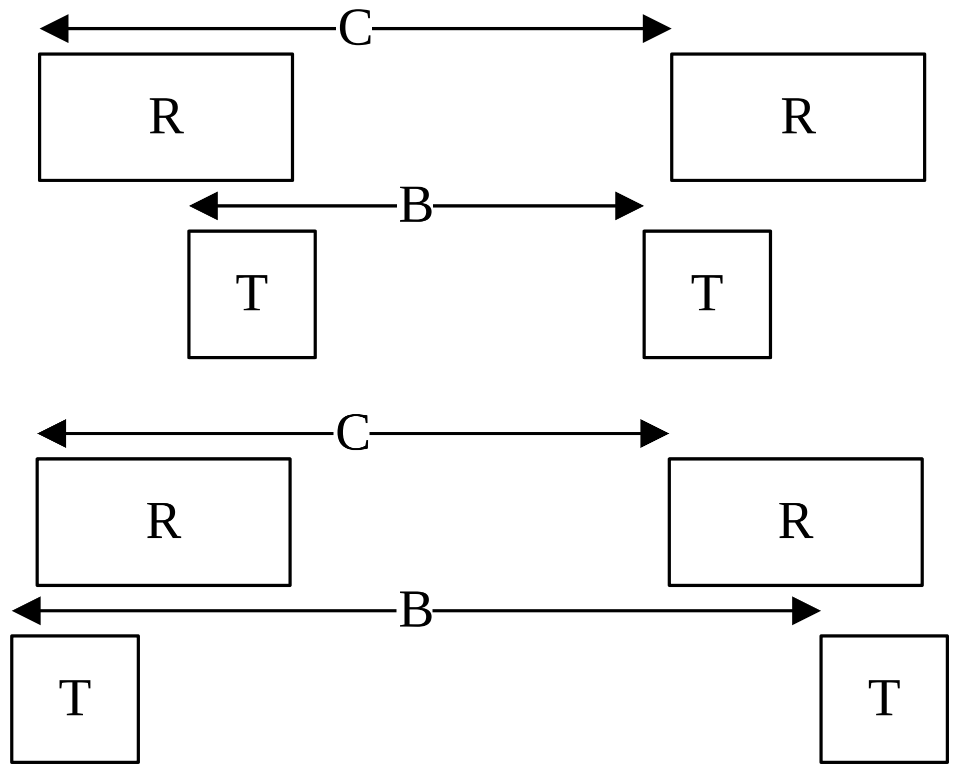


Sequential, Pseudo-concurrent and Concurrent Scanning
Beacon period (B) : 102.4 ms
Beacon length (T): 0.5 ms
R=0.3 × C
Concurrent channels (l): 5
Sequential
Pseudo-concurrent
Concurrent
Expected Scanning Time (s)
Cycle Time (C) (ms)
0
5
10
15
20
25
30
35
40
45
50
85
90
95
100
105
110
115
120
125
130
135

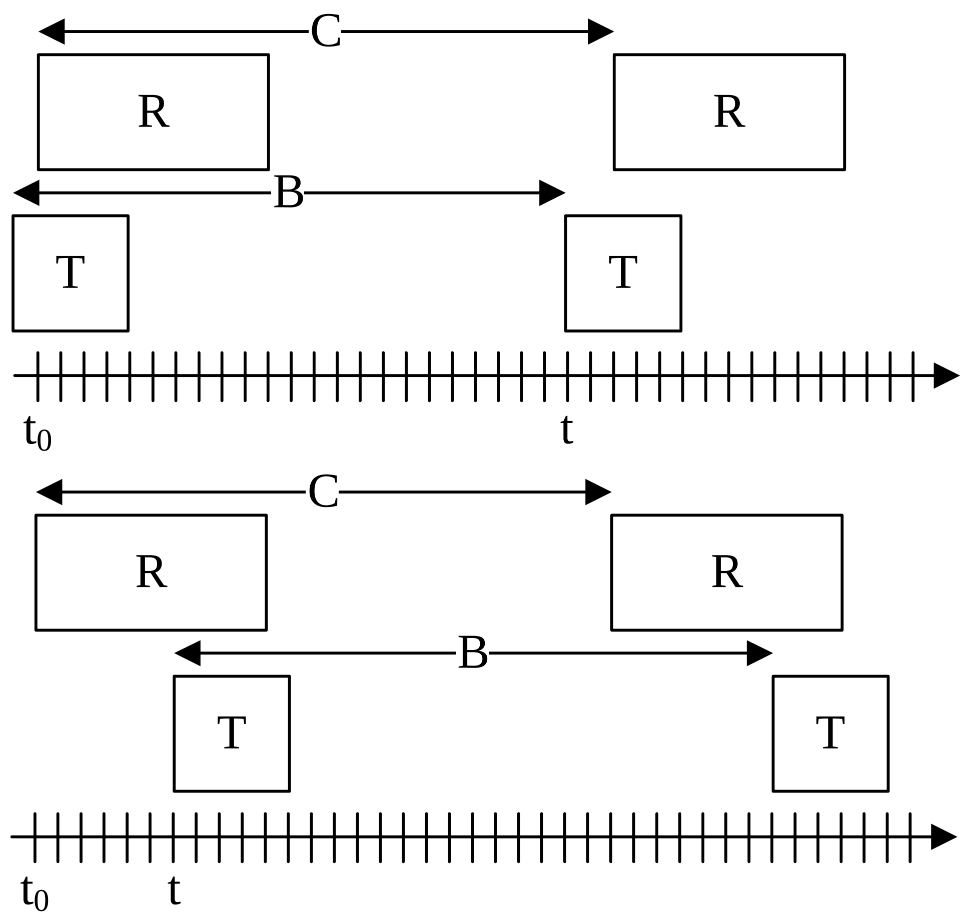
Thank you!

## Sequential scanning - Assumption $R - |C - B| \geq 2 \cdot T$

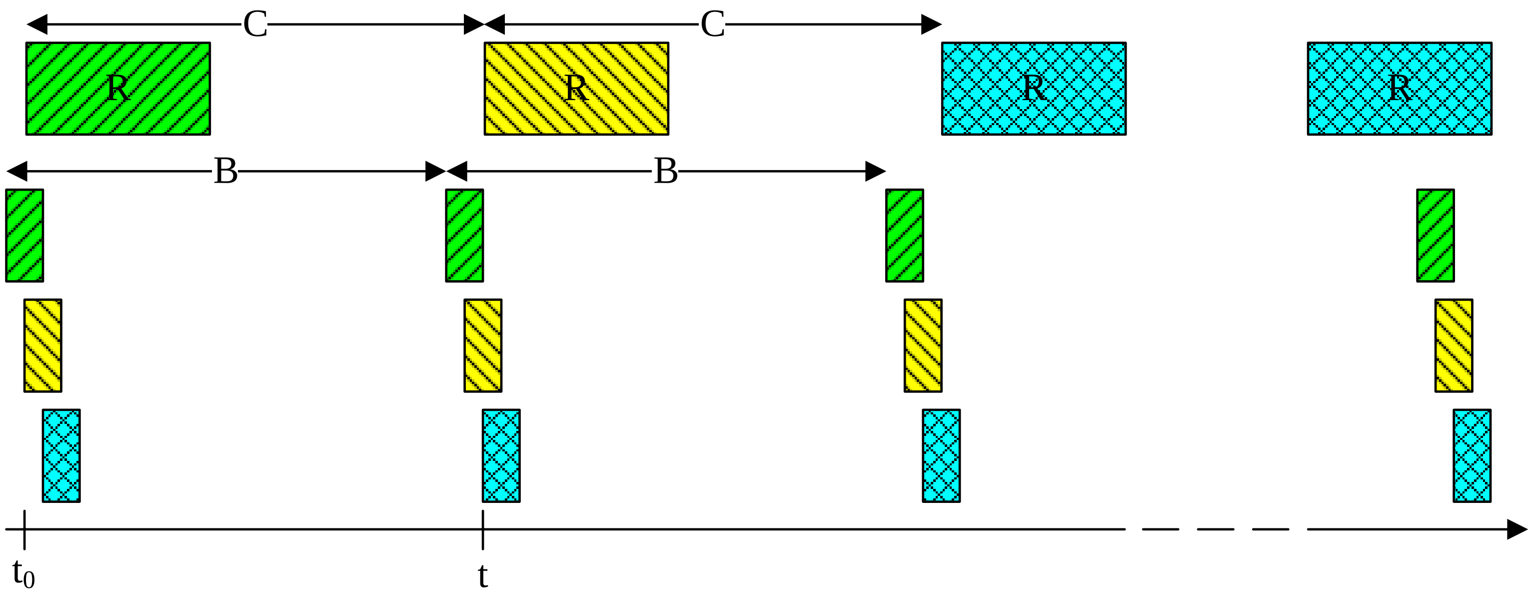
## Counter examples:



## Sequential scanning - Worst cases: $C > B$ or $C < B$



# Worst case of pseudo-concurrent scanning: $C > B$



## Pseudo-concurrent scanning, selection of $m$: $C > B$