

Controlled Greedy Sleep, a One-hop Neighboring Knowledge Based k-Coverage Algorithm

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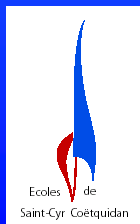
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- ❑ **Introduction**
 - ❑ k-coverage problem in wireless sensors networks
 - ❑ CGS algorithm presentation

- ❑ **Performance criteria and topology**
 - ❑ Performance criteria
 - ❑ Ring topology
 - ❑ Analytical computation of global performance criteria

- ❑ **Evaluation**
 - ❑ Coverage quality
 - ❑ Cost coverage
 - ❑ Global performance

- ❑ **Conclusions**
 - ❑ CGS best use cases
 - ❑ Open problems

k-Coverage problem in wireless sensor networks

- Introduction
- Performance criteria and topology
- Evaluation
- Conclusion

• **Objective** : each point of the area under observation must be covered by at least k sensors simultaneously as long as possible

• **Applications** : target location, localization services with high discrimination and robustness

Characteristics of a wireless sensor	
Drawbacks	Advantages
<ul style="list-style-type: none">• Limited in :<ul style="list-style-type: none">-Computational speed-Electrical power (energy)-Communication range-Measurement range• Frequent failures	<ul style="list-style-type: none">• Inexpensive• Easy to produce• Easy to install

Limited contribution {

{ **Possible overdosing**

- **Solutions** :
- Alternating between active and asleep states
 - Scheduling of sensor subsets (a NP hard problem)

CGS algorithm presentation (1/3)

- Introduction
- Performance criteria and topology
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Principles

- Distributed scheduling algorithm
- Based on one-hop neighborhood knowledge
- Time is sampled in periods
- Space under observation is divided in regions
- Computation of a priority metric at every period
- Exchange of control messages at the beginning of each period

Objectives

- Ensure the maximal k -covered area ratio of the space under observation
- Extend the network lifetime: Reduce energetic and computational costs

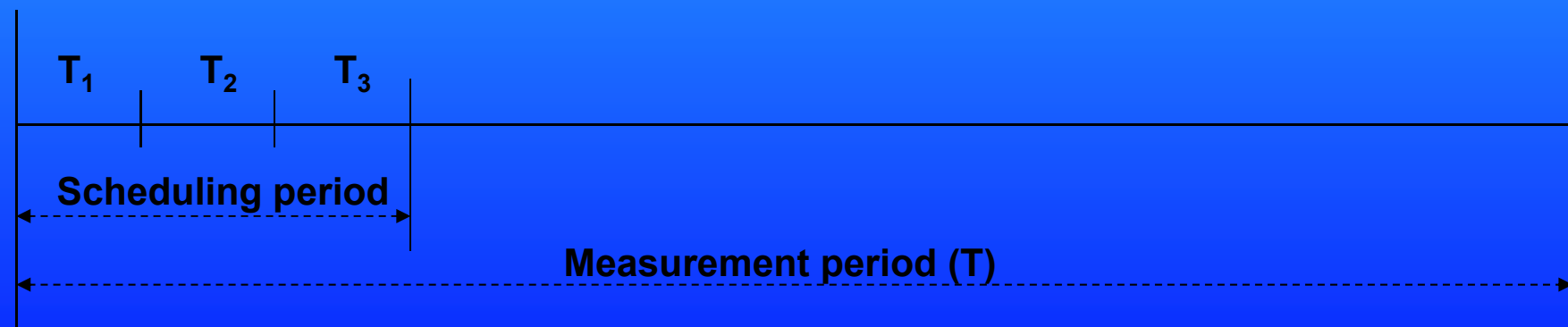
CGS algorithm presentation (2/3)

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- Performance criteria and topology
- Evaluation
- Conclusion.

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Each scheduling period is divided in 3 phases with their own message :

1. **Hello phase**: one-hop neighborhood discovering
2. **STD Phase** : priority metric (Shoot Time Delay) computation and diffusion to one-hop neighbors
3. **Awake phase**: decision computation and diffusion to one-hop neighbors



CGS algorithm presentation (3/3)

- Introduction
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•Drossiness factor (D_f) and Shoot Time Delay (STD) computation :

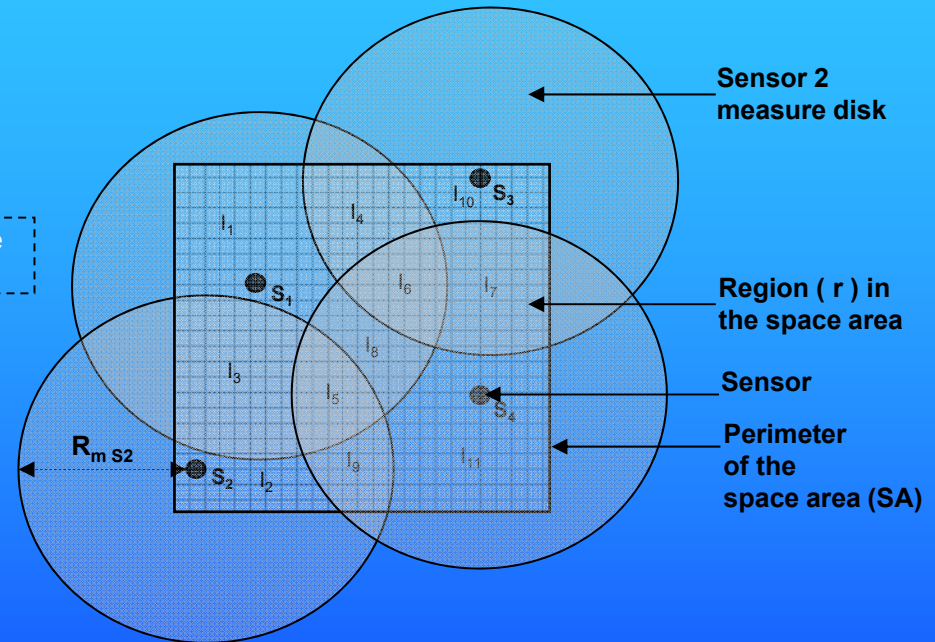
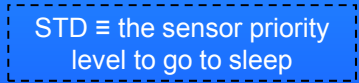
$$Df_{s_i} = \frac{1}{E_r^\gamma} \cdot \sum_{r \in (Dm_{s_i} \cap SA)} \frac{1}{C_r - k}, \text{ if } C_r > k, \forall r$$

else : -1.



$$STD_{s_i} = (1 - Df_{s_i}) \cdot T_3, \text{ if } Df_{s_i} \neq -1$$

else : -1.



•Sensor conditions to go to sleep :

- STD \neq -1 and has expired
- all of its regions can be k-covered by its neighbor sensors which :
 - declared that they stay active (STD = -1, or have sent an Awake message)
 - have a higher STD value

Performance criteria

- Coverage quality (Q)** : k-covered ratio of the space area

$$Q = \frac{1}{N_r} \sum_{i=k}^{i=N_s} N_{r_i}$$

Annotations for the equation above:

- Total number of regions (points to N_r)
- Total number of sensors (points to $i=N_s$)
- Number of regions i-covered (points to N_{r_i})

- Coverage cost (C)** : number of active sensors

$$C_{rel} = \frac{C}{N_{s_{min}}}$$

Annotations for the equation above:

- Relative coverage cost (points to C_{rel})
- Minimal number of active sensor to provide the full k-coverage (Q=1) (points to $N_{s_{min}}$)

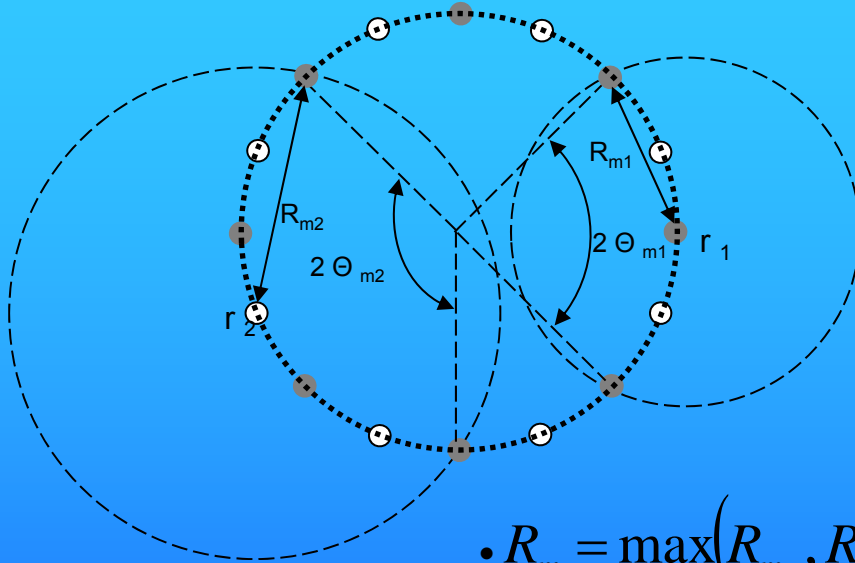
Computed on a period

- Global performance (P(Q))**: Duration of service providing with a minimal coverage quality value of Q

$$Pn(Q) = \frac{P(Q)}{P_{max}(Q)}$$

Normalized global performance (points to $Pn(Q)$)

Ring topology



- Region
- Asleep sensor
- Active sensor
- N_s : total number of sensors
- $N_{sa\ min}$: minimal number of active sensors
- O_v : overdosing (here $O_v = N_s / N_{sa\ min} = 2$) sensors (here $N_{sa\ min} = 8$)
- R_m : measurement radius
- R_c : communication radius
- Θ_m : equivalent angle to R_m .
- Θ_c : equivalent angle to R_c .

$$\bullet R_m = \max(R_{m_1}, R_{m_2}) = 2 \cdot r \cdot \sin\left(\frac{\theta_{R_m}}{2}\right) = 2 \cdot r \cdot \sin\left(\frac{\Pi \cdot (O_v \cdot k + 1)}{2 \cdot N_s}\right)$$

$$\bullet \text{Connectivity condition} \Rightarrow \theta_{R_c} \geq 2 \cdot \theta_{R_m} \Rightarrow R_c \geq 2 \cdot r \cdot \sin(\theta_{R_m})$$

➤ If N is the maximum number of active periods for each sensor, the network can provide a maximum of $N \cdot O_v$ periods with full k-coverage ($Q=1$) and with a minimal coverage cost ($C_{rel}=1$)

➤ In the ring topology all the performance criteria can be obtained analytically

Analytical computation of global performance criteria (1/2)

Maximum Global performance with the full k-coverage :

$$P_{\max}(1) = N \cdot O_v \cdot T_N, \text{ with } T_N \text{ the duration of each period}$$

Global energy balance for a sensor :

- E_o : initial energy level
- E_C : energy spent in communications and computations
- E_M : energy spent in measurement
- E_r : energy remaining, $E_r = E_o - (E_C + E_M)$

•Periodic energy balance for a sensor :

- $\Delta E_M \approx (dE_M/dt) \cdot T_N$: energy consumed in measurement during an active period
- e_{ca}/e_{cs} : energy consumed in communications and computations during an active/sleeping period → **does not depend on T_N**

Find the realistic T_N value according to E_C/E_M and N

Analytical computation of global performance criteria (2/2)

- Introduction
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• Let's us assume that $\alpha_N = E_{C(N)}/E_{M(N)}$

Since $E_C(N) = N \cdot E_C(1)$, and $E_C(1) = \frac{E_o}{1/\alpha_1 + 1}$, then :

Case where each sensor can stay active during one period only

$$\alpha_N = \frac{\alpha_1 \cdot N}{1 - \alpha_1 \cdot (N - 1)}, \text{ for } 1 \leq N \leq \frac{E_o}{E_c(1)}$$

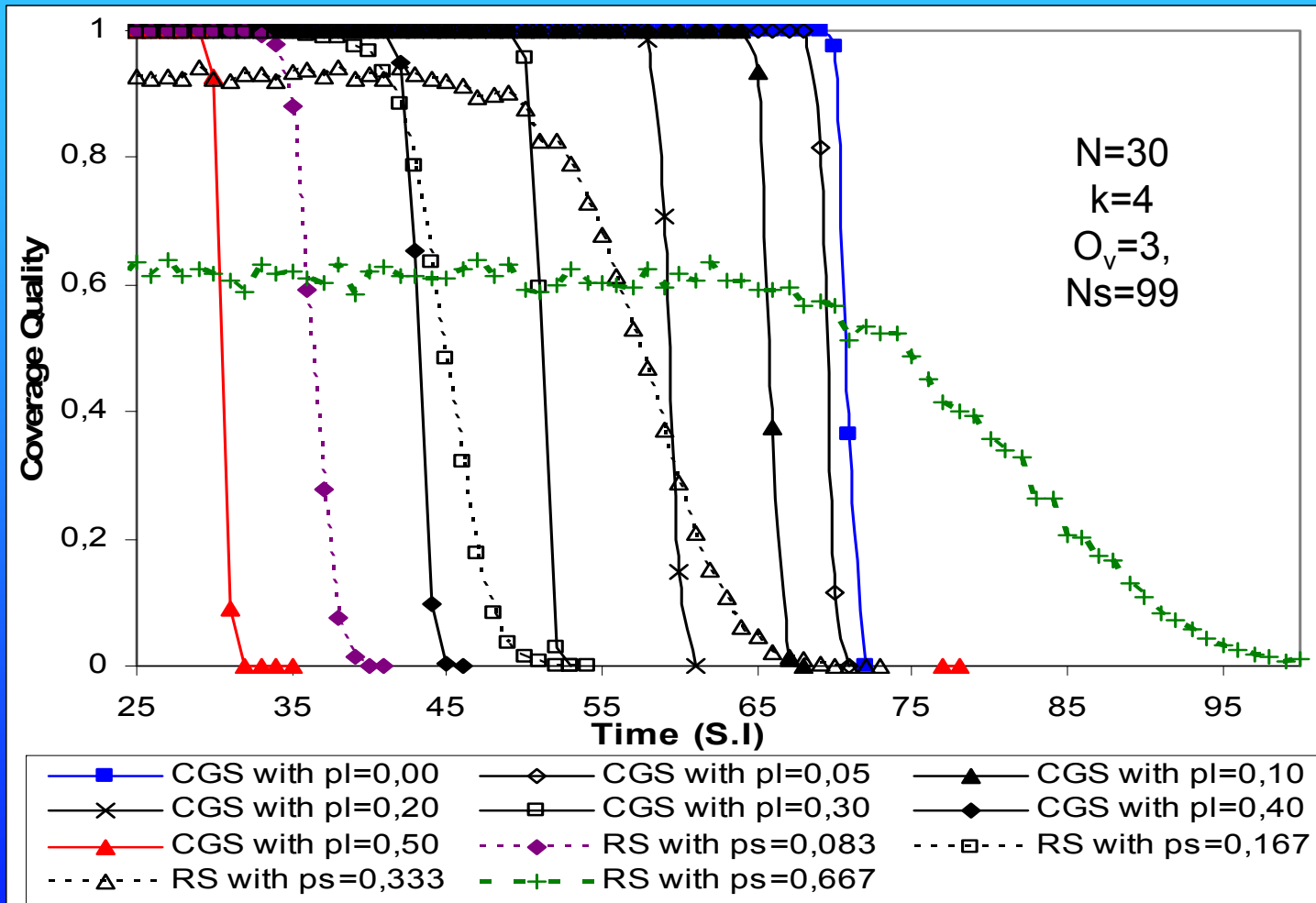
If $\alpha_1 = 0$ then $\alpha_N = 0$ and so $N \cdot T_N$ is constant (T_{ref}) whatever N , because $E_C(N) = 0$.
If we assume that $T_{ref} = 1$, then $dE_M/dt = E_o$, and consequently :

$$T_N = \frac{1}{N \cdot (1 + \alpha_N)} \Rightarrow P_{max}(1) = \frac{O_v}{1 + \alpha_N}$$

Coverage quality

- Introduction
- Performance criteria and topology
- **Evaluation**
- Conclusion

Coverage quality as a function of time and message loss probability (p_l) for CGS and Random Scheduling (RS).



➤ CGS has been first designed to ensure a full k-coverage

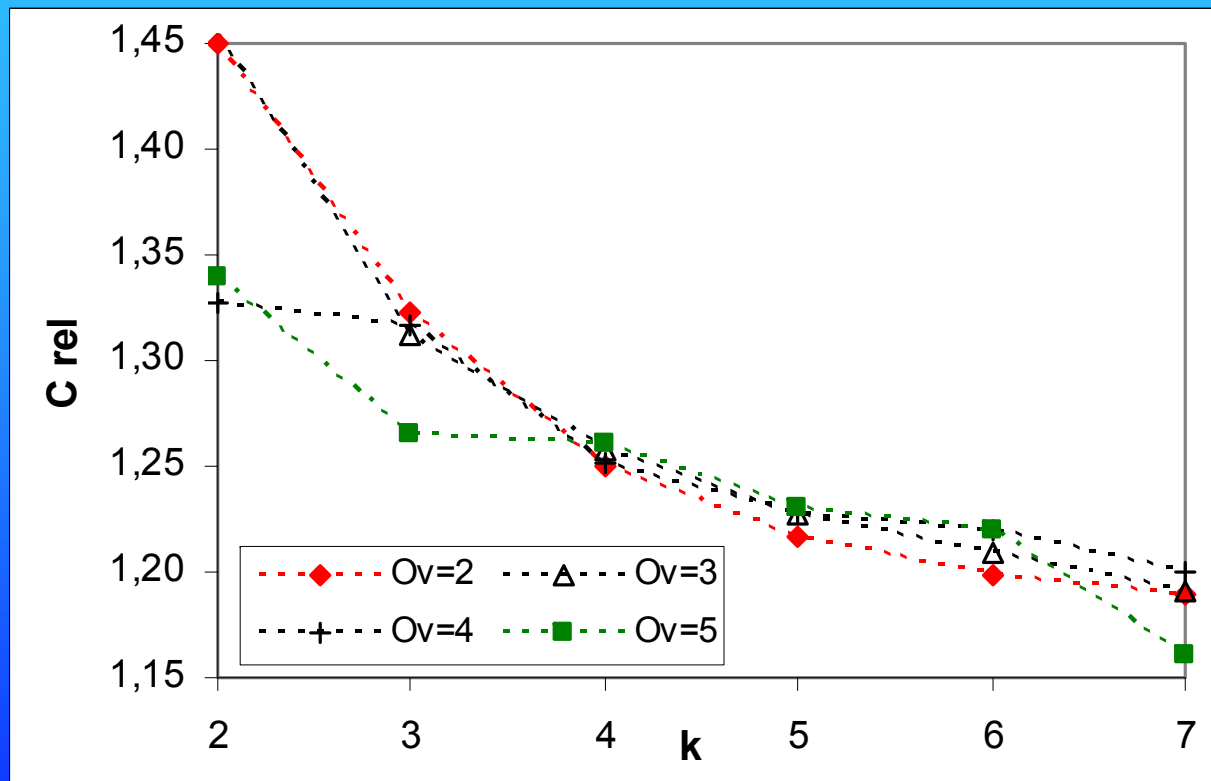
➤ CGS is robust against message losses

Coverage cost

- Introduction
- Performance criterias and topology
- **Evaluation**
- Conclusion

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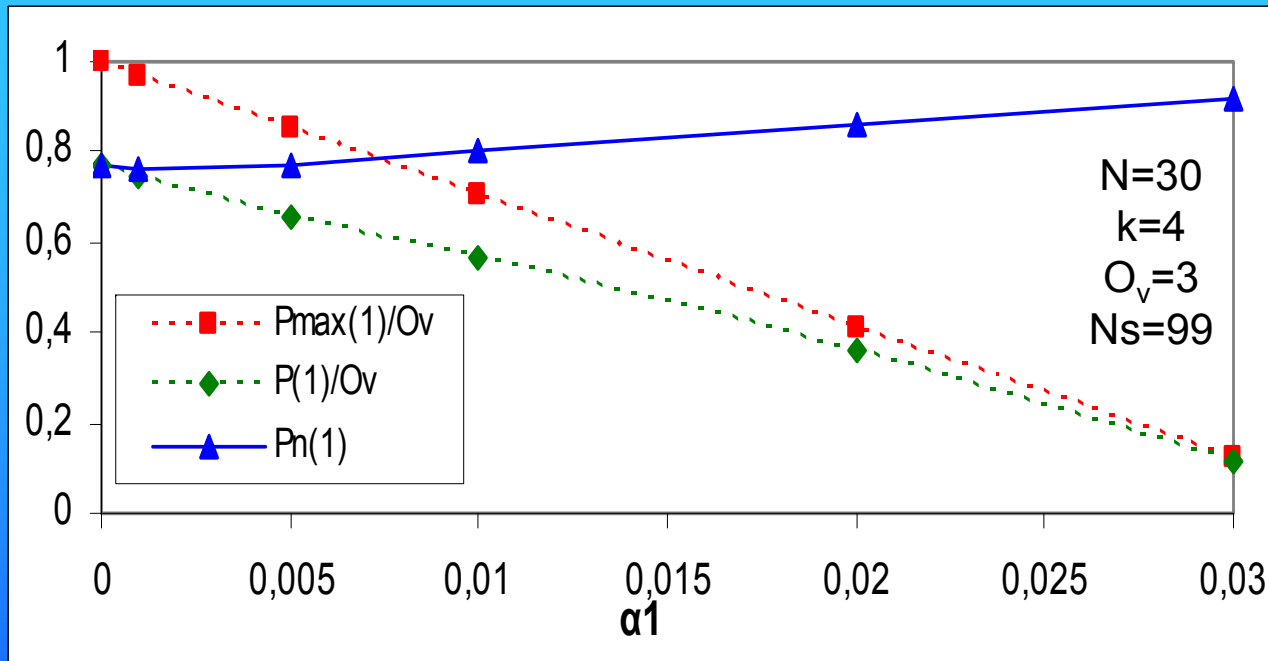
Relative coverage cost ($\langle C_{rel} \rangle$) as a function of O_v and k ,
for $N = 30$



➤ CGS relative cost coverage decreases when the number of one-hop neighbors increases ($\approx 2 \cdot O_v \cdot k$)

Global performance

- Introduction
- Performance criteria and topology
- **Evaluation**
- Conclusion



➤ Analytical computation of global performance criteria is good

➤ Normalized global performance increases when communication costs increases

➤ Coverage cost influence on global performance decreases when communication costs increases

α_1	0.000	0.001	0.005	0.010	0.020	0.030
α_{30}	0.00	0.03	0.18	0.42	1.42	6.92
T_{30}	0.033	0.032	0.028	0.023	0.013	0.004
$\langle C_{rel} \rangle$	1.25	1.26	1.26	1.26	1.26	1.25

Conclusions

- Introduction
- Performance criteria and topology
- Evaluation
- Conclusion**

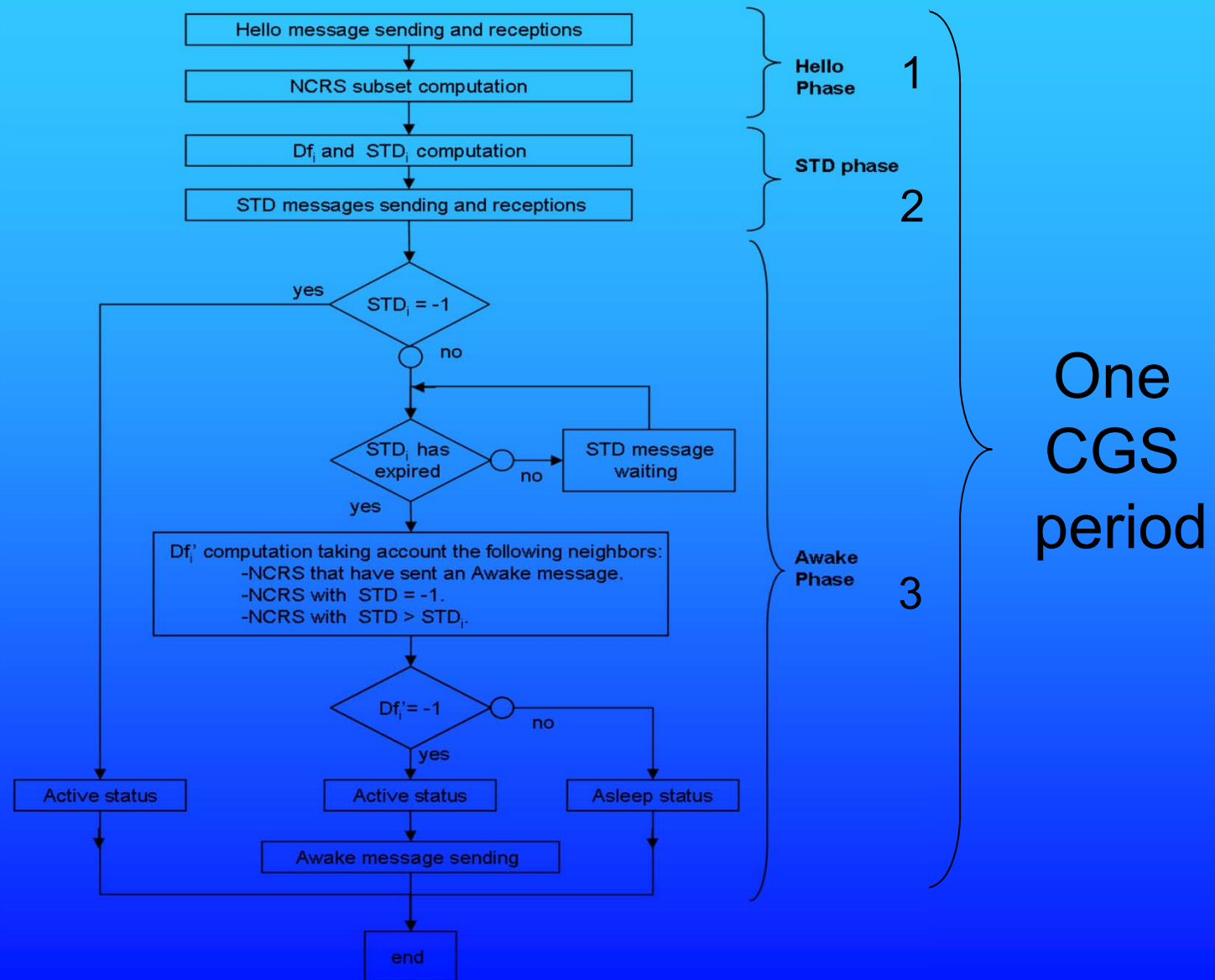
- **CGS best use cases:**

- Full k-coverage must be ensured
- High k and overdosing values (high number of one hop neighbors)
- Significant communication costs

- **Open problems**

- Sensor location inaccuracy
- Overdosing / Measurement and communication radius
- Security

Annex 1: CGS algorithm



Annex 2 : maximum global performance computation.

- The initial energy level of each sensors.
- The wished number of active periods of each sensor (N).
- The maximal total number of periods ($N \cdot O_v$) with the full k-coverage ($Q = 1$). This number value is equal to $N \cdot O_v$ because there are O_v disjoint minimal subsets of active sensors.
- The energy spent in communications and measurements for each sensor.
- Each period duration (T_N).

Basically, we can say that $P_{max}(1) = N \cdot O_v \cdot T(N)$, so the main task is to determine $T(N)$.

Energy balance of an Op-sensor for a period:

- $\frac{dE_M}{dt_a}$: energy consumed in measurements per time unit.
- e_{ca} : energy consumed in communications and computations during an active period.
- e_{cs} : energy consumed in communications and computations during a sleeping period.
- e_m : energy consumed to send a message to a maximum distance of R_c .

With our previous hypothesis we can say that:

- $e_{ca} \approx 3 \cdot e_m$ because an awake sensor has sent at most 3 messages (Hello, STD messages plus an Awake message when $Df \neq -1$).
- $e_{cs} \approx 2 \cdot e_m$ because an asleep sensor has sent 2 messages (Hello and STD messages).

After $N \cdot O_v$ periods, we have for each sensor the following energy balance:

- $E_M = \frac{dE_M}{dt_a} \cdot N \cdot T_N$
- $E_C = ((N-1) \cdot O_v + i) \cdot e_{cs} + N \cdot e_{ca}$, where i is the rank of the subset during the last O_v periods ($1 \leq i \leq O_v$).

Global energy balance:

- E_0 : initial energy level.
- E_R : remaining energy level.

We can now compute the period duration T_N . An interesting α_1 value is 0. That means all energy is consumed in measurements and that $N \cdot T_N$ will be constant ($\forall N \in \mathbb{N}^*$). We name this constant the reference time (T_{ref}).

Also, if $\alpha_1 = 0$ then $\alpha_N = 0 \forall N \in \mathbb{N}^*$ (see equation 8). In this case we can say that: $P_{max}(1) = O_v \cdot T_{ref}$.

Since:

$$E_0 = E_M \cdot (\alpha_N + 1) = \frac{dE_M}{dt_a} \cdot N \cdot T_N \cdot (\alpha_N + 1) \quad (9)$$

If $N = 1$ and $\alpha_1 = 0$ then $E_0 = E_M = \frac{dE_M}{dt_a} \cdot T_{ref}$. If we assume that $T_{ref} = 1$ (for normalization) we can say that:

$$\frac{dE_M}{dt_a} = E_0 \quad (10)$$

$$\text{Thus: } E_M = \frac{dE_M}{dt_a} \cdot N \cdot T_N = \frac{E_0}{1 + \alpha_N}$$

Then:

$$T_N = \frac{1}{N \cdot (1 + \alpha_N)} \quad (11)$$

Consequently:

$$P_{max}(1) = O_v \cdot N \cdot T_N = \frac{O_v}{1 + \alpha_N} \quad (12)$$

Because $0 \leq \alpha_1 \leq \alpha_N$ and according to our references,

Annex 3 : more simulation results about CGS and Random Scheduling coverage quality

p_l	0.00	0.05	0.1	0.2	0.30	0.40	0.50
$P(Q = 1)$	70	69	65	58	50	41	30
$P(Q > 0)$	73	72	69	62	54	47	33
$P(0 < Q < 1)$	3	3	4	4	4	6	3
\bar{Q}	0.99	0.98	0.97	0.98	0.97	0.95	0.97
σ_Q	0.07	0.11	0.14	0.11	0.14	0.20	0.16

TABLE I
CGS COVERAGE QUALITY Q AND GLOBAL PERFORMANCES AS A FUNCTION OF MESSAGES LOSS PROBABILITY WITH $N = 30$, $Ov = 3$, AND $k = 4$.

p_s	0.083	0.167	0.333	0.667
$P(Q = 1)$	27	0	0	0
$P(Q > 0)$	42	55	72	109
$P(0 < Q_s < 1)$	15	55	72	109
\bar{Q}	0.90	0.99	0.74	0.47
σ_Q	0.28	0.005	0.33	0.23

TABLE II
RANDOM SCHEDULING GLOBAL PERFORMANCES ($P(Q)$) AS A FUNCTION OF SLEEPING PROBABILITY p_s VALUES WITH $N = 30$, $Ov = 3$, AND $k = 4$.

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