Swarms of Artificial Platelets for Emergent Hole Detection and Healing in Wireless Sensor Networks

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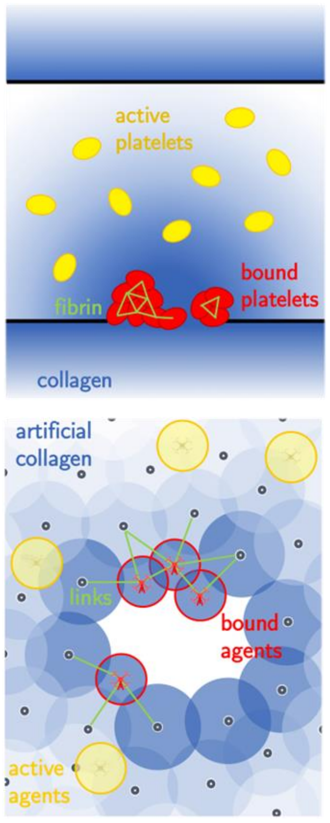
Introduction



- Wireless Sensor Networks (WSNs) are used for **sensing** and monitoring a Region of Interest (ROI)
- Full coverage is jeopardized by suboptimal deployment of nodes and their **failures**, causing ***holes*** in the **coverage**
- Existing approaches unrealistically assume availability of mobile or redundant nodes in the WSN to ***heal*** the holes
- We designed an **emergent** algorithm to restore the coverage using a **swarm** of resource-constrained **agents** with **reduced sensing capabilities** [1]

KEY IDEA

We see the ROI as endothelium and the coverage holes as injuries. We **draw inspiration from** the behaviour exhibited by platelets during **coagulation** to **design** the **controller** of the **swarm** used to restore the coverage

- Each agent is a non-holonomic **robot** with **sensing** and **communication** capabilities, equipped with **a Range and Bearing** (RaB) sensor to perceive the environment

Fig. 1: Parallelism between biological (top) and swarm (bottom) space

Our approach

In a nutshell

The agents, modeled as artificial platelets, follow **three rules** relying only on **local** information:

Activation — Adhesion — Cohesion

Bio-Inspiration	Swarm Control
Inactive platelets flowing in vessels	Swarm **resting** in release points (RPs) in **inactive** state
Platelets activated by exposure to collagen, introduced by the injury	Upon hole detection, agents are **activated** by **exposure** to **artificial collagen** (AC)
High concentration of collagen means proximity to the wound	Agents use RaB to reach the hole, **following** the **gradient of the concentration of AC**
Platelets adhere to injury border	Agents use **geometric criteria** to **compute** and **move** toward **locally optimal positions**
Prostacyclin prevents adhesion outside the wound	Candidate positions are **filtered** to **remove** those **already covered** and **ranked** with heuristics based on distance
Platelets secrete fibrin as plug stabilizer	Upon deployment, agents **establish connections** with the network
Adhered platelets release ADP to recruit other platelets	Upon deployment, agents **update** their **value** of **concentration of AC, attracting** other agents
Upon healing, the clot dissolves and platelets return to flow in the vessels	When the faulty nodes are fixed, the agents **return to their** RPs or fly to **cover new holes**

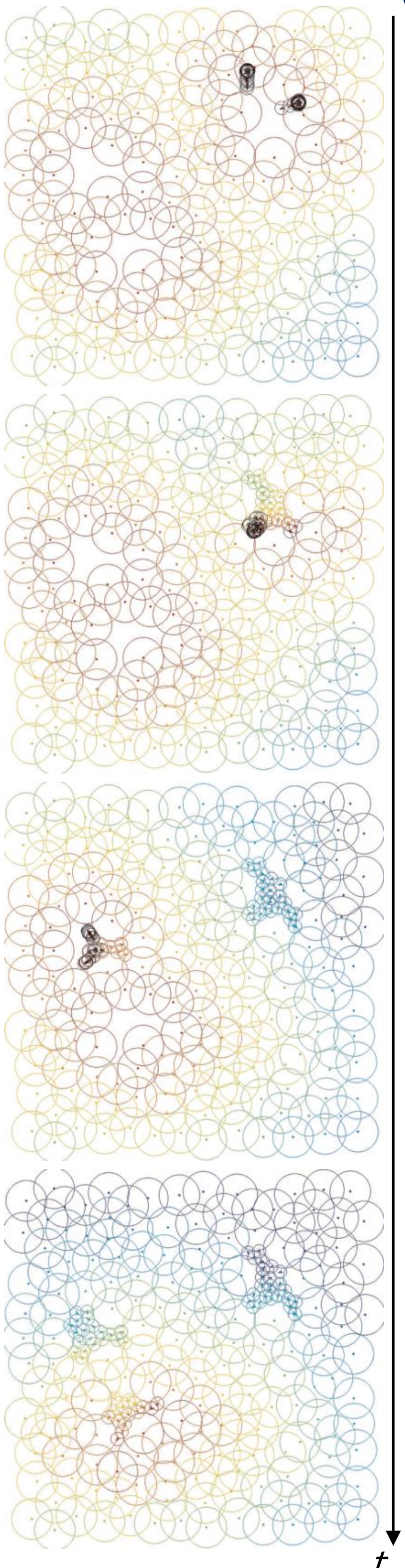
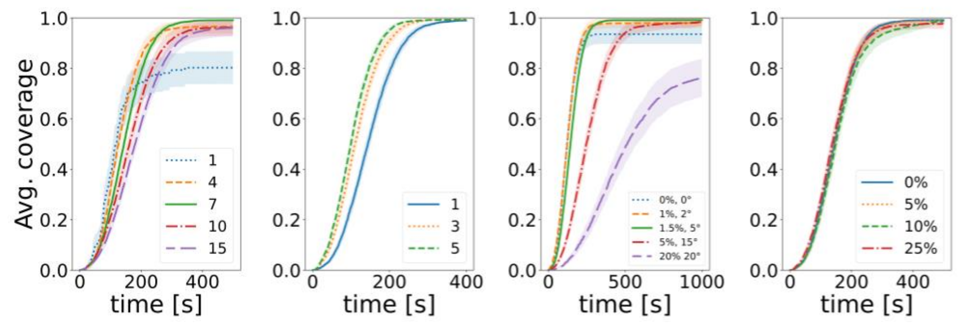


Fig. 2: Snapshots of a multi-hole healing process.

Results

- We developed and released **HDHSim** [2], a multi-agent **simulator** for hole detection and healing applications
- We evaluated our approach for **scalability** and **robustness**, measuring the fraction of the area of the holes **covered** by the swarm
- For all experiments, the approach achieves **high coverage**
- The algorithm demonstrates **good healing capacity** even in case of **massive** node **failures** (Fig. 3a)
- A **speed-up** in healing process is obtained using **multiple RPs** (Fig. 3b)
- The method shows good **robustness** also in case of extremely **noisy perceptions** (Fig. 3c) and against severe **agent failure** (Fig. 3d)



(a) Nr. failures (b) Nr. RPs (c) RaB errors (d) Agent failure

Fig. 3: Average coverage over time.

- Our approach **outperforms** *state-of-the-art* algorithms such as DHDR [3] and FSHR [4] (Fig. 4)

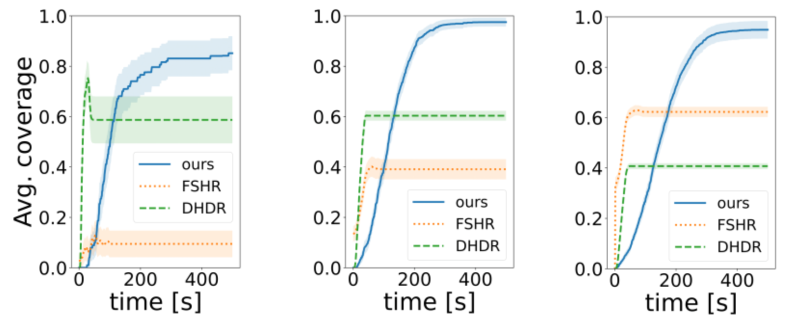


Fig. 4: Average coverage over time when increasing hole size.

	DHDR		FSHR		ours	
P_f	Avg. %	95% CI	Avg. %	95% CI	Avg. %	95% CI
0	60.38	1.96	38.80	3.76	97.53	1.62
0.05	33.48	4.62	34.77	3.69	97.13	1.76
0.1	8.29	6.34	34.23	3.65	97.58	1.63
0.25	5.10	6.80	30.90	3.64	97.12	1.59

- Contrarily to our approach, **[3]** and **[4]** show a **drop** in the **coverage** for higher rates of **agent failure**

Fig. 5: Average coverage when increasing failure probability.

Conclusions

- We developed an algorithm for **detecting** and **healing holes** in the coverage, relying on **limited perception** and **sensing** capabilities
- The **cooperation** of thousands of **platelets** during coagulation is a good **inspiration** for **swarm control**, leading to emergent behaviours
- Swarm-based algorithms are intrinsically flexible, scalable, and robust, being **exceptionally suitable** in **time-sensitive** and **mission-critical** scenarios

What's next

- Include obstacles
- Model battery level
- Collision avoidance
- New positioning approaches

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References

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[2] G. Simionato, F.A. Galatolo, 2023. https://github.com/GiadaSimionato/HDHSim.git
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[4] L. Yan, Y. He, and Z. Huangfu. 2020. *A fish swarm inspired holes recovery algorithm for wireless sensor networks*. International Journal of Wireless Information Networks