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Bistatic Architecture Provides Extended Coverage and System Reliability in Scatter Sensor Networks

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Outline

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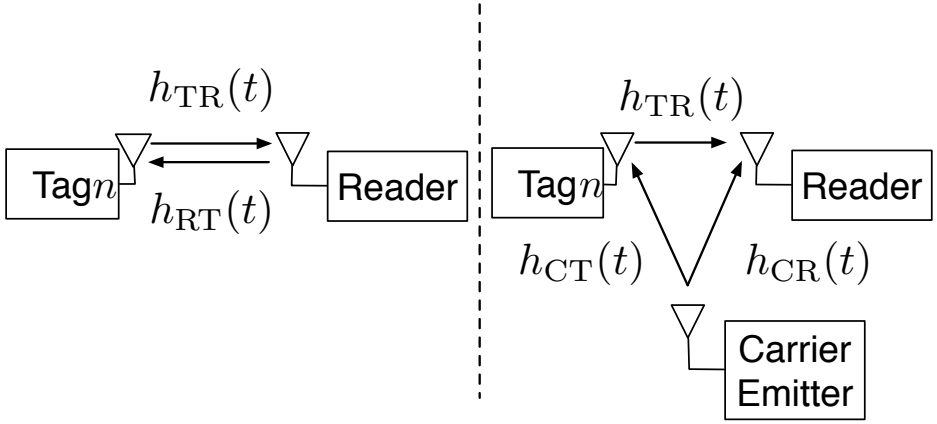
Scatter-Radio Architecture Analysis

Scatter-Radio Networks for Precision Agriculture

- Urgent need for low power, ultra-low cost environmental sensing.
- Classic WSN approaches are costly.
- **Solution**: *Scatter*-radio networks!

Scatter-Radio Network Architectures



A) Bistatic Architecture:
- Carrier Emitter - Reader are dislocated[1].
- Unidirectional links.

B) Monostatic Architecture:
- Carrier Emitter - Reader are co-located.
- Bidirectional link.
- Commonly used by the industry (RFIDs)

[1]Kimionis, J., Bletsas, A., Sahalos, J.N.: Bistatic backscatter radio for tag read-range extension. In: IEEE Intl. Conf. on RFID-Technologies and Applications (RFID-TA), Nice, France (November 2012).

Bistatic System Model

The average received power of the n-th user at the reader:

$$P^n \triangleq \eta^n L^n_{\mathrm{CT}} L^n_{\mathrm{TR}} P_{\mathrm{C}}, \tag{1}$$

The compound channel, affecting the user, is given by:

$$h^n = h^n_{\mathrm{CT}} h^n_{\mathrm{TR}} \tag{2}$$

The channels $h^n_{\mathrm{CT}} h^n_{\mathrm{TR}}$ are independent.

Monostatic System Model

The average received power of the n-th user at the reader:

$$P^n \triangleq \eta^n (L_{\mathrm{RT}}^n)^2 P_{\mathrm{R}}, \tag{3}$$

The compound channel, affecting the user, is given by:

$$h^n = (h_{\mathrm{RT}}^n)^2 \tag{4}$$

The channels $h_{\mathrm{RT}}^n, h_{\mathrm{TR}}^n$ are fully dependent.

Performance Analysis

Probability of Error Under ML Coherent Detection

For a given channel h^n, the conditional probability of error of both monostatic and bistatic is given by:

$$\Pr(e \mid h^n) = Q\left(\frac{a^n \left\|\mathbf{x}_0^n - \mathbf{x}_1^n\right\|_2}{\sqrt{2\,\mathcal{N}_0}}\right) = Q\left(a^n\,\overline{\mathrm{SNR}^n}\right), \tag{5}$$

where $a^n \triangleq |h^n|$ and the received SNR:

$$\overline{\mathrm{SNR}^n} = \sqrt{\frac{P^n T}{\mathcal{N}_0}} \tag{6}$$

Bit-Error Rate: Bistatic Case

By using the Chernoff bound:

$$\Pr(e\,|\,\text{Tag } n) \leq \left(\frac{2}{\overline{\text{SNR}^n}}\right) \exp\left\{\frac{2}{\overline{\text{SNR}^n}}\right\} \Gamma\left(0, \frac{2}{\overline{\text{SNR}^n}}\right) \tag{7}$$

The order of decay of the probability of error is:

$$\lim_{\overline{\text{SNR}^n} \to \infty} \frac{\log\left[\left(\frac{2}{\overline{\text{SNR}^n}}\right) \exp\left\{\frac{2}{\overline{\text{SNR}^n}}\right\} \Gamma\left(0, \frac{2}{\overline{\text{SNR}^n}}\right)\right]}{\log\ \overline{\text{SNR}^n}} = -1. \tag{8}$$

The upper bound decays with $\frac{1}{\overline{\text{SNR}^n}}$ and hence, the diversity order is 1.

Bit-Error Rate: Monostatic Case

The probability of error of the monostatic system is given by:

$$\Pr\left(e \,|\, \text{Tag } n\right) = \frac{1}{2} - \exp\left\{\frac{1}{2\,\overline{\text{SNR}^n}}\right\} Q\left(\frac{1}{\sqrt{\overline{\text{SNR}^n}}}\right) \tag{9}$$

The order of decay of the error probability is:

$$\lim_{\overline{\text{SNR}^n}\to\infty} \frac{\log\left[\Pr(e \mid \text{Tag } n)\right]}{\log\ \overline{\text{SNR}^n}} = -\frac{1}{2}. \tag{10}$$

The probability of bit error decays with $\frac{1}{\sqrt{\overline{\text{SNR}^n}}}$ and hence, the diversity order is $\frac{1}{2}$.

Probability of Outage

For both architectures, the signal-to-interference-plus-noise ratio (SINR):

$$\mathrm{SINR}^n \triangleq \frac{\frac{1}{R} g^n P^n}{\frac{1}{R}\mathrm{I} + \mathcal{N}_0} \tag{11}$$

The outage event, $\mathrm{SINR}^n \leq \Theta$, occurs when the SINR drops below a predetermined threshold Θ.

Bistatic Case

Theorem

For the bistatic architecture, the probability of outage is bounded by:

$$\Pr\left(SINR^n \leq \Theta\right) \leq 1 - 2\left(\frac{\Theta \mathrm{A} + \Theta R \mathcal{N}_0}{P^n}\right)^{\frac{1}{2}} \mathrm{K}_1\left(2\left(\frac{\Theta \mathrm{A} + \Theta R \mathcal{N}_0}{P^n}\right)^{\frac{1}{2}}\right)$$

Monostatic Case

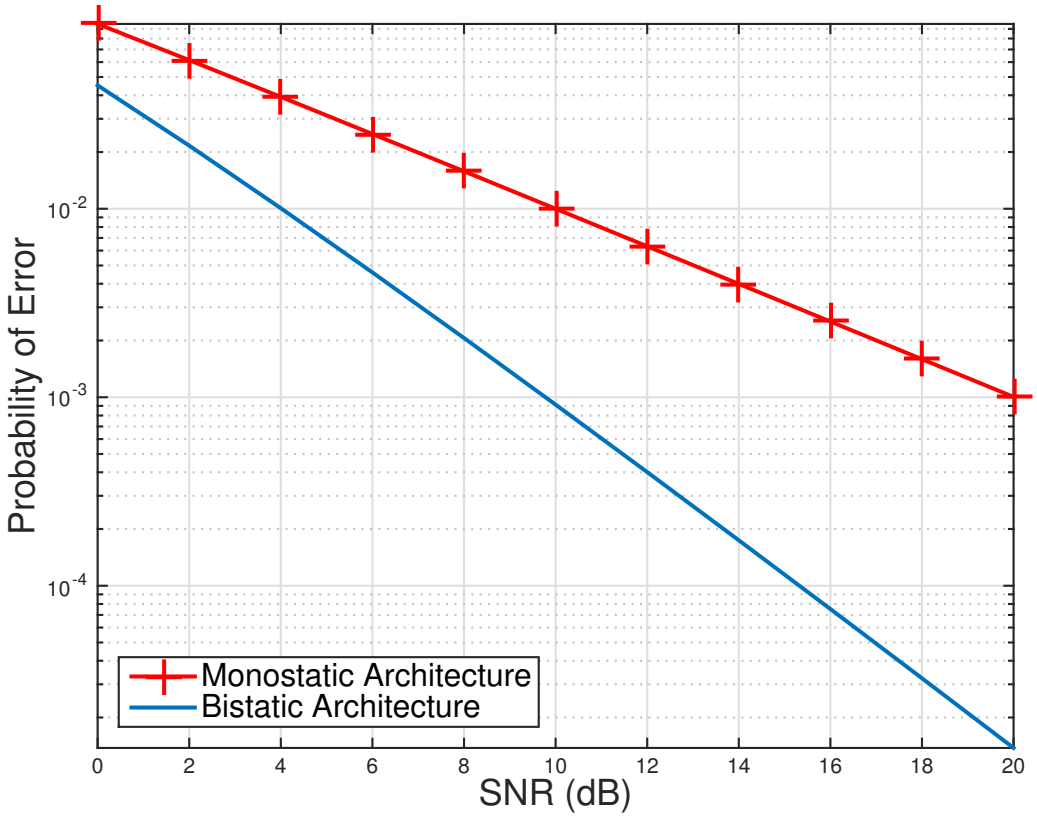
Theorem

For the monostatic architecture, the probability of outage is given by:

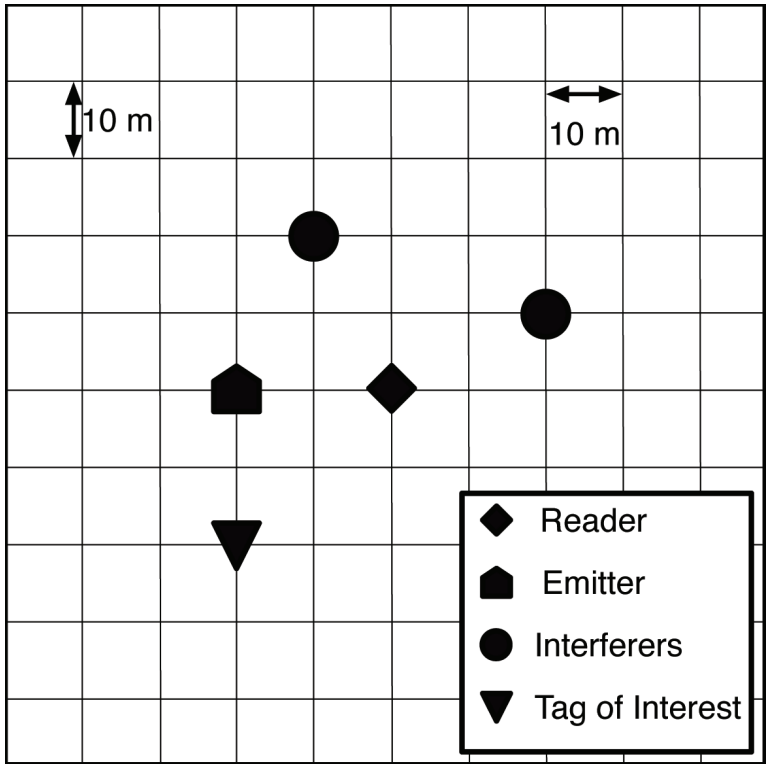
$$\Pr\left(SINR^n \leq \Theta\right) \leq 1 - \exp\left\{-\left(\frac{2\Theta A + \Theta R \mathcal{N}_0}{P^n}\right)^{\frac{1}{2}}\right\}$$

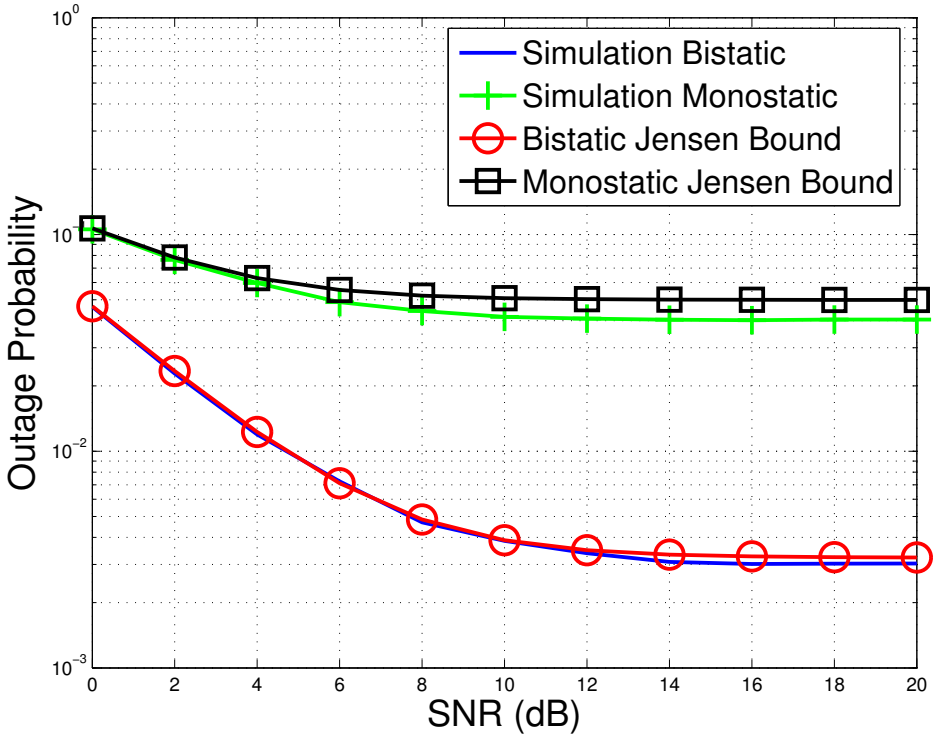
Numerical Results

Probability of Error

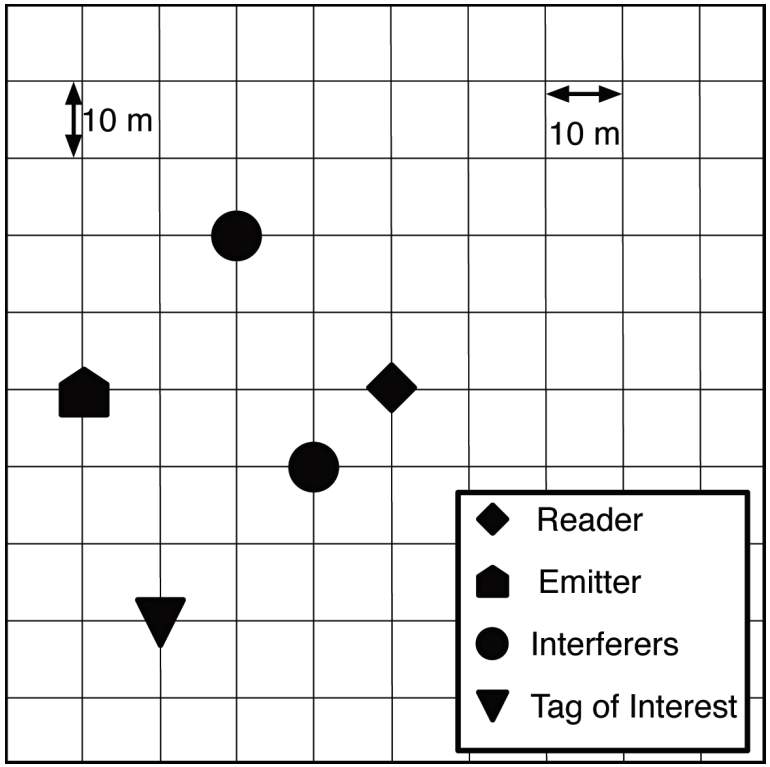


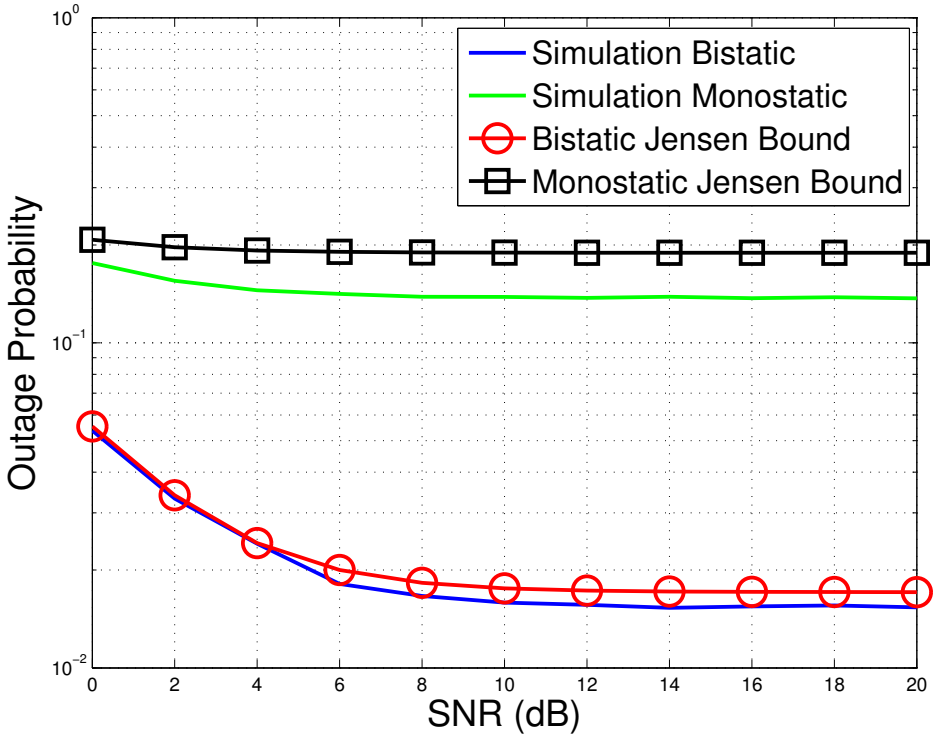
Probability of Outage (1)





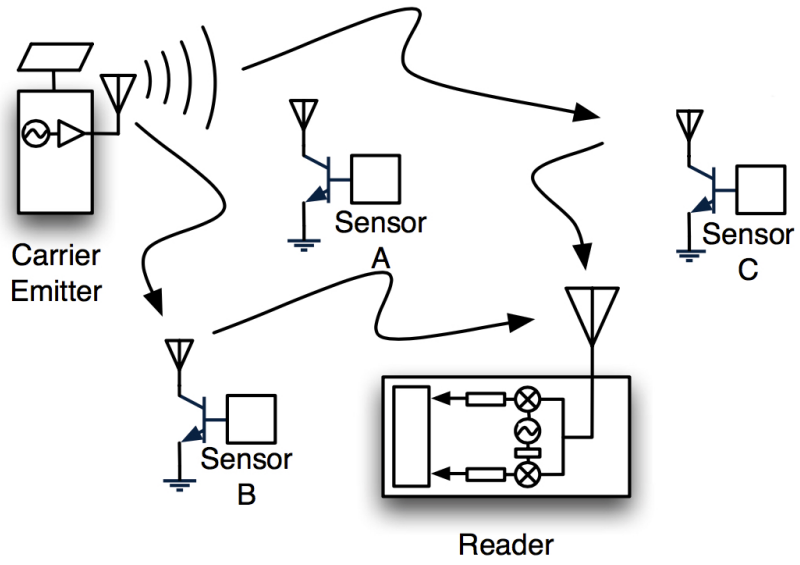
Probability of Outage (2)





Bistatic Digital Scatter-Radio Network

Bistatic Scatter-Radio Network



- Multiple low-cost, low-power tags.
- Multiple carrier emitters.
- Single Software-Defined Radio reader.

Digital Scatter Tag

Our approach:

- Low bit rate[2].
- Energy assisted tags.

Utilize 8-bit MCU for:

- Data sensing.
- Channel coding[3].
- B-FSK modulation.

Ranges $\geq$ **150** m! With $P_{Emitter} = 13$ dBm and Bit-Error Rate = 5%

[2] Vannucci, G. Bletsas, A., Leigh, D.: A software-defined radio system for backscatter sensor networks. IEEE Trans, Wireless Commun. 7(6) (June 2008) 2170-2179
[3]P. N. Alevizos, N. Fasarakis-Hilliard, K. Tountas, N. Agadakos, N. Kar- gas, and A. Bletsas, “Channel coding for increased range bistatic backscatter radio: Experimental results,” in Proc. IEEE RFID Techn. and Applications (RFID-TA), Tampere, Finland, Sep. 2014, pp. 38–43.

Bistatic Digital Scatter-Radio Network Video Demonstration

Demonstrating a 25 tag scatter-radio network, sensing soil moisture.

Conclusion

Conclusion

- Provided in-depth analysis of the system models for both monostatic and bistatic architectures.
- Developed closed form expressions for the probability of error under ML detection and diversity order for the single user case and Jensen bounds for the probability of outage for the multiple user case.
- The bistatic architecture surpasses the monostatic one, in terms of coverage and performance.
- A 25 node digital scatter-radio network was constructed.
- References:

Thank You!

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