113-2 電工實驗（通信專題）

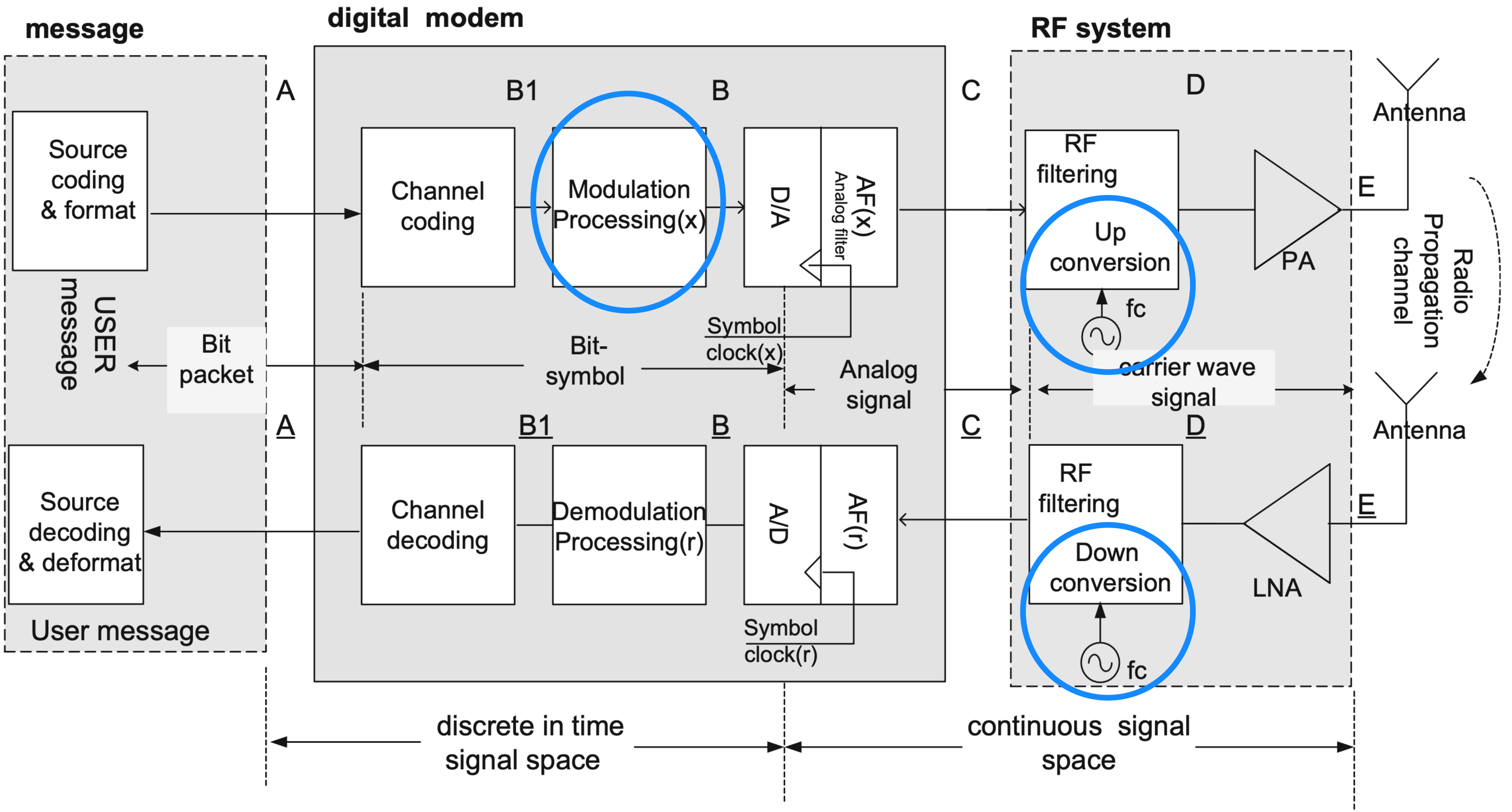
Demodulation

Chia-Yi Yeh (葉佳宜)
ycyyeh@ntu.edu.tw

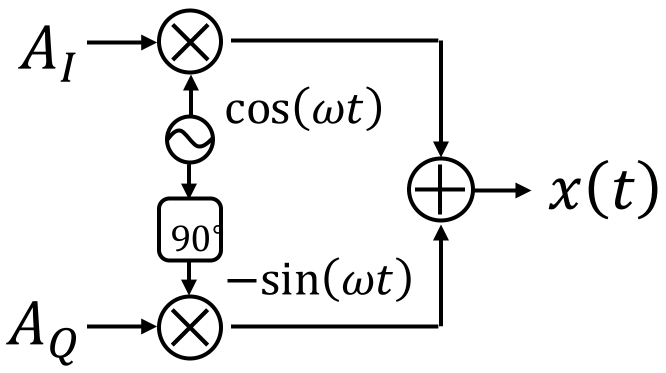
Department of Electrical Engineering
National Taiwan University

Review

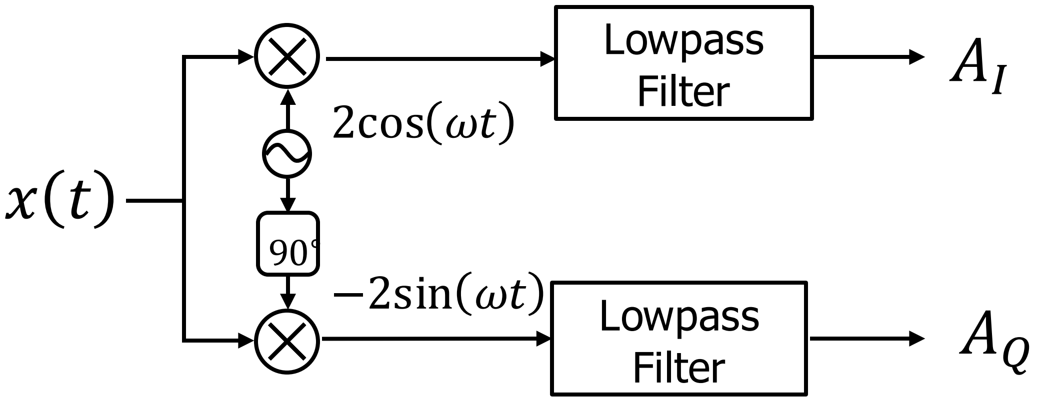
Digital Radio Communication System Block Diagram



Upconversion & Downconversion



Upconversion



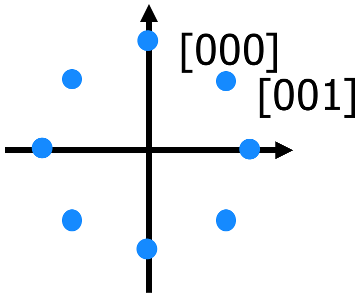
Downconversion

Digital Modulation = mapping data bits to (I,Q) values

Digital Modulation

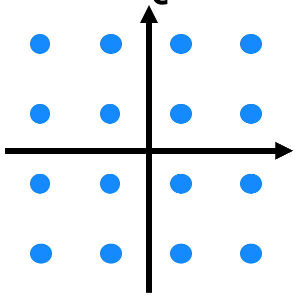
Phase Shift Keying (PSK)

8-PSK



Quadrature Amplitude Modulation (QAM)

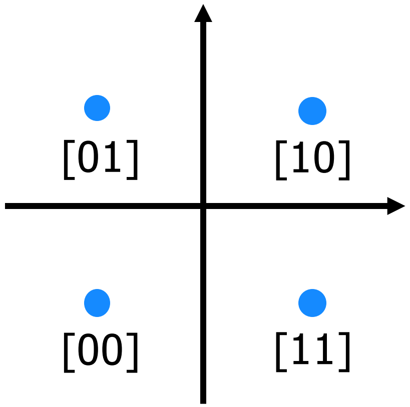
16-QAM



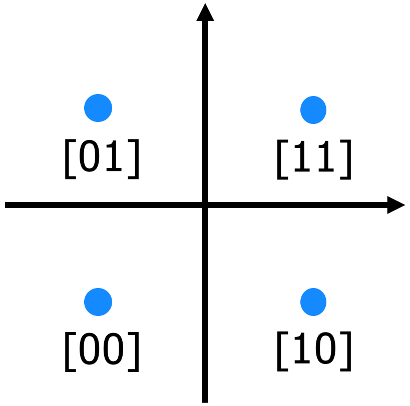
Gray Coding

Neighboring symbols differ by only one bit

Extra performance at zero cost (this is rare!)



Natural-coded QPSK

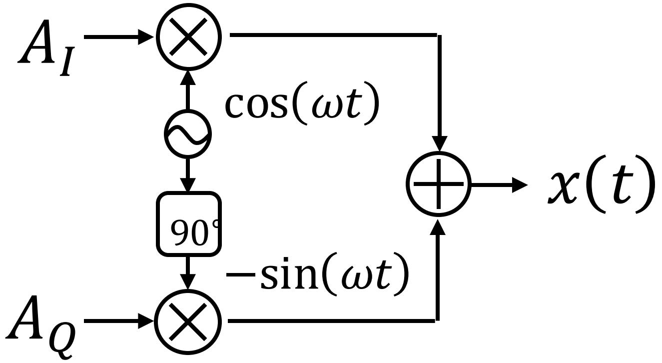


Gray-coded QPSK

Upconversion: Three Representations

$$x(t) = A\cos(2\pi f_c t + \theta) \qquad (1)$$

Polar Cosine wave modulated by a baseband signal with amplitude (A) and phase (θ)



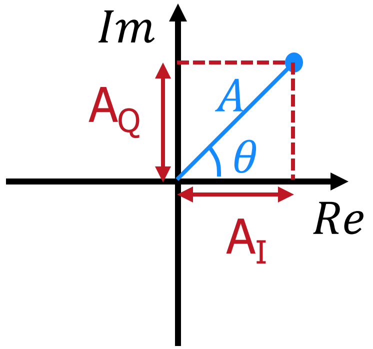
Hardware implementation

$$= A_I\cos(2\pi f_c t) - A_Q\sin(2\pi f_c t) \qquad (2)$$

Rectangular $A_I = A\cos(\phi)\,,A_Q = A\sin(\phi)$

$$= Re\{[A_I + jA_Q]\,e^{j2\pi f_c t}\} \qquad (3)$$

Complex envelope $u = A_I + jA_Q$



$A_I + jA_Q$: Complex envelope

Upconversion: Frequency Domain

$$x(t) = Re\{[A_I + jA_Q]\, e^{j2\pi f_c t}\}$$

Let $u(t) = A_I + jA_Q$

$$= Re\{u(t)\, e^{j2\pi f_c t}\}$$

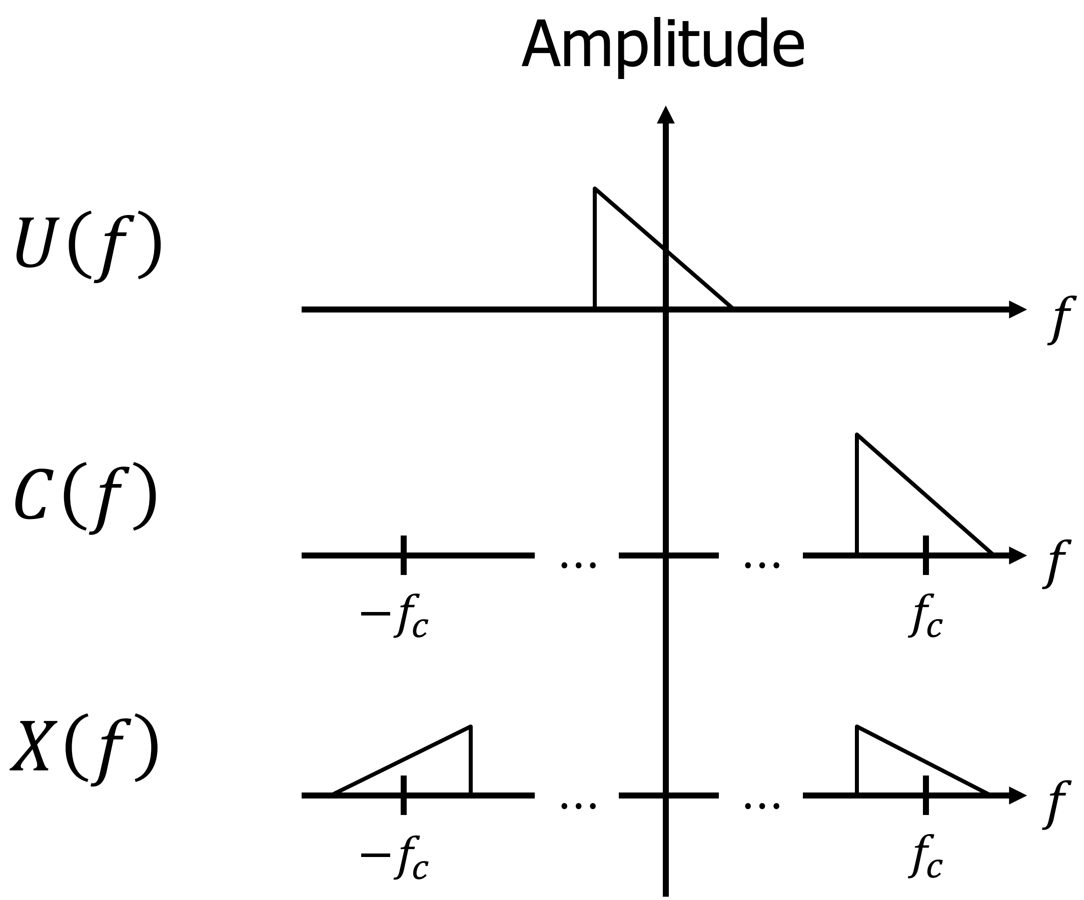
Let $c(t) = u(t)\, e^{j2\pi f_c t}$

$$= Re\{c(t)\}$$

$$\Updownarrow$$

$$X(f) = \frac{1}{2}(\, C(f) + C^*(-f)\,)$$

where $C(f) = U(f - f_c)$



Downconversion: Frequency Domain

$y(t) = x(t) \cdot 2e^{-j2\pi f_c t}$

Let $\mathrm{d}(t) = x(t)\, e^{-j2\pi f_c t}$

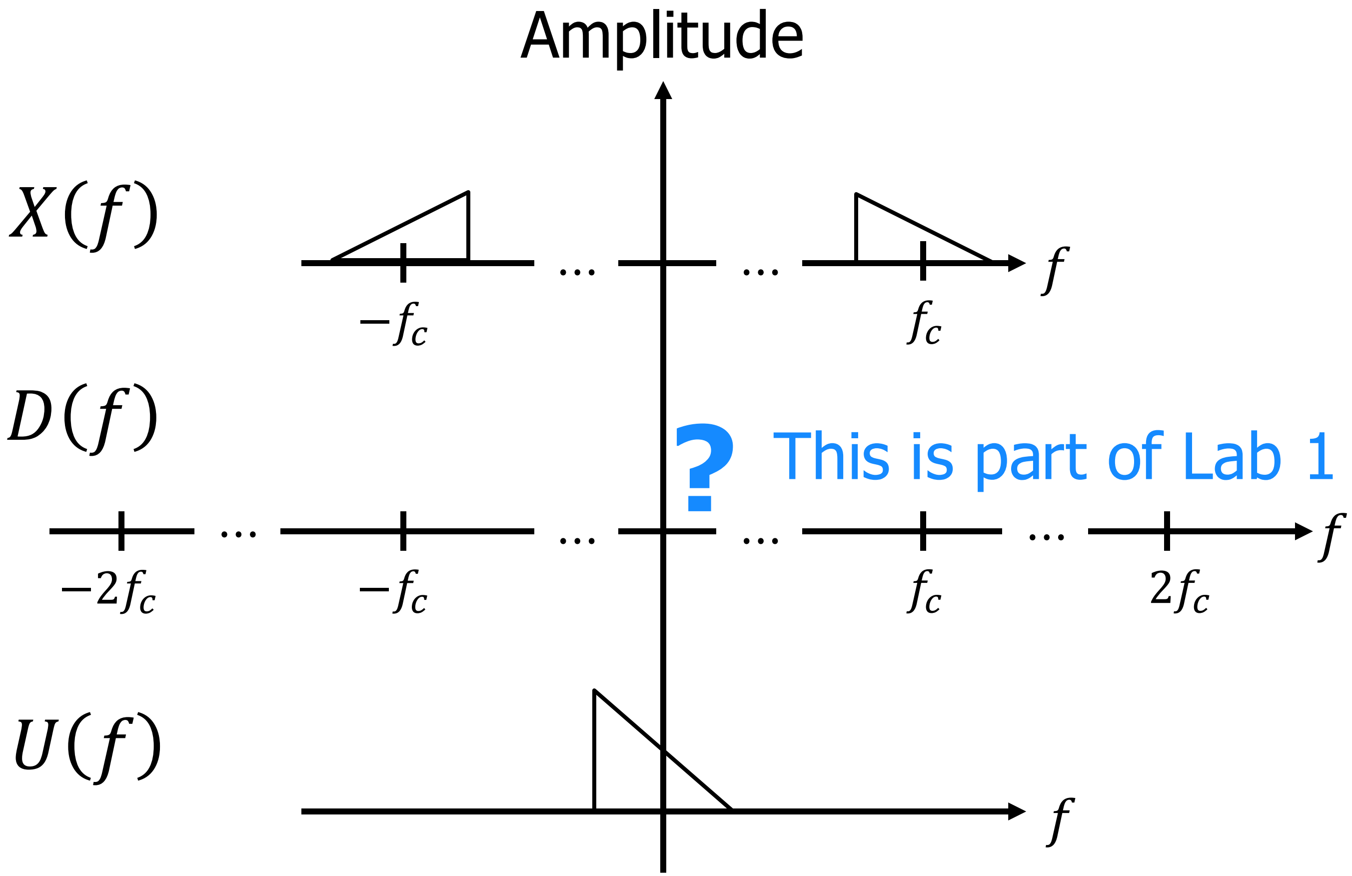
Lowpass filtering

$u(t)$

$\Updownarrow$

$U(f) = lowpass\,\{\, 2 \cdot D(f)\, \}$

where $\mathrm{D}(f) = X(f + f_c)$

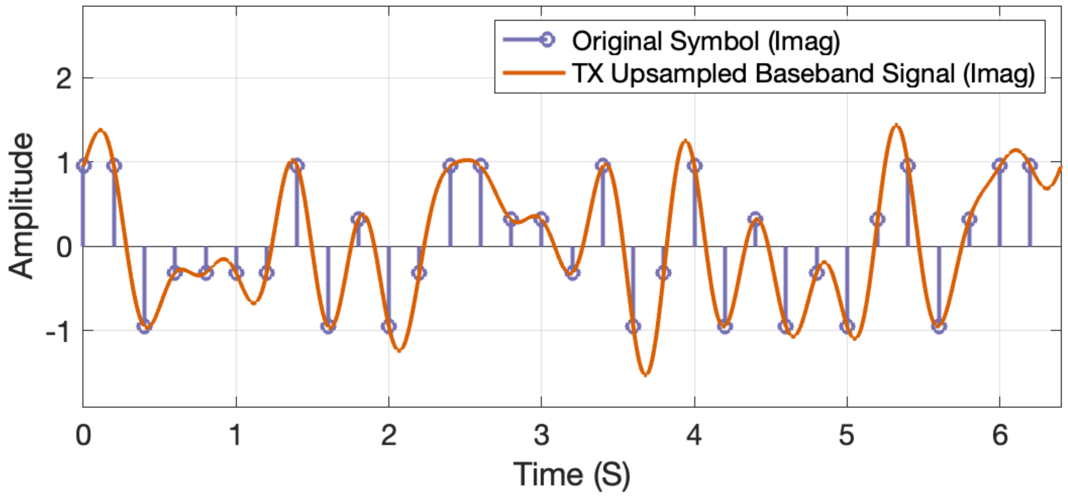


Lab 1 (Due Sep. 16)

Part 1: IQ modulation from baseband to RF

Noiseless: time & freq domain signal

Additive noise: correctly emulate targeted SNR



Part 2: Demodulation

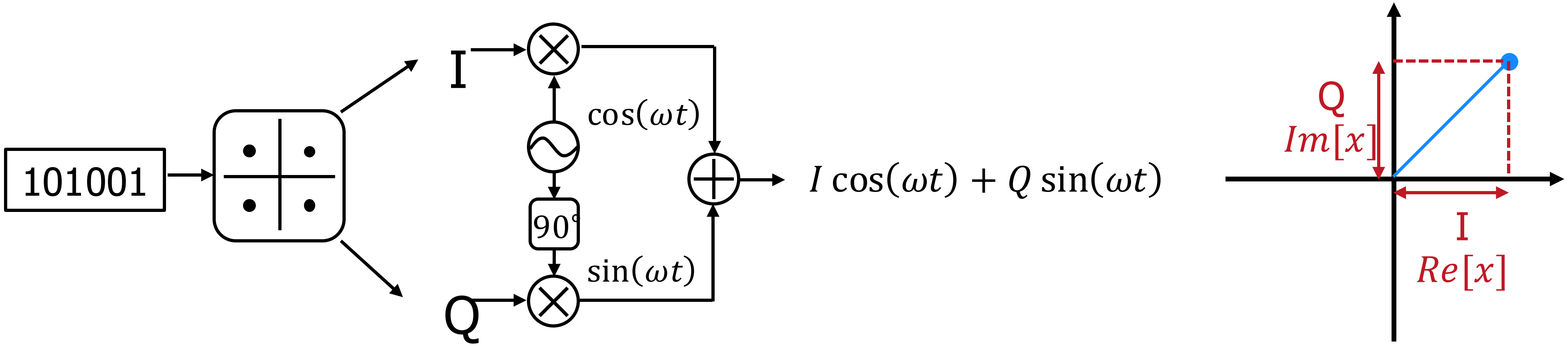
Write your script to simulate AWGN transmissions.

- BER by Monte Carlo simulation
- Optimal decoding with MAP

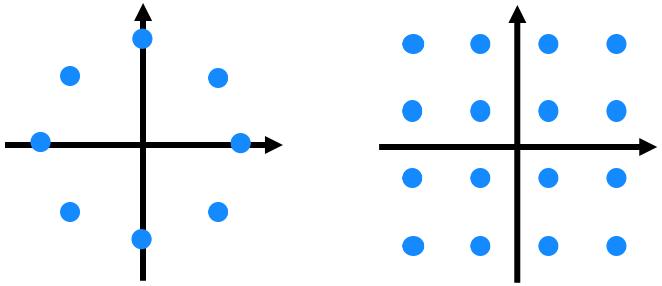
Demodulation

Last week

Modulation = mapping data bits to (I,Q) values

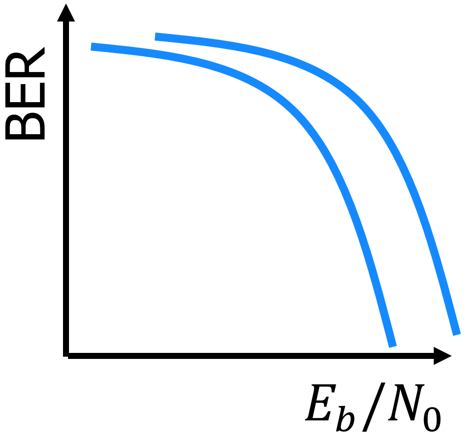


PSK & QAM

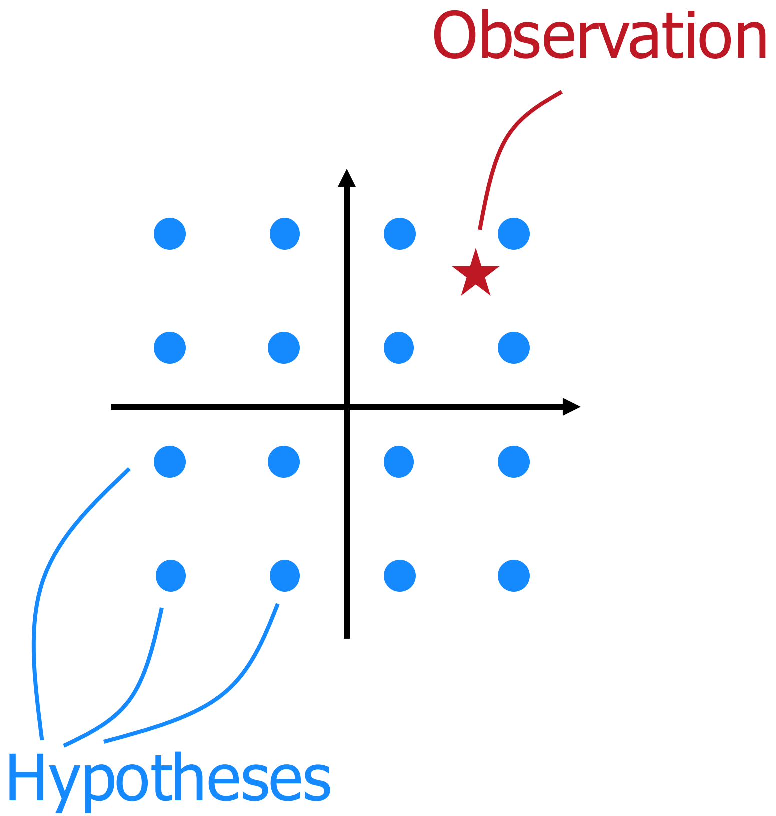


How?

Bit Error Rate



Optimal Demodulation



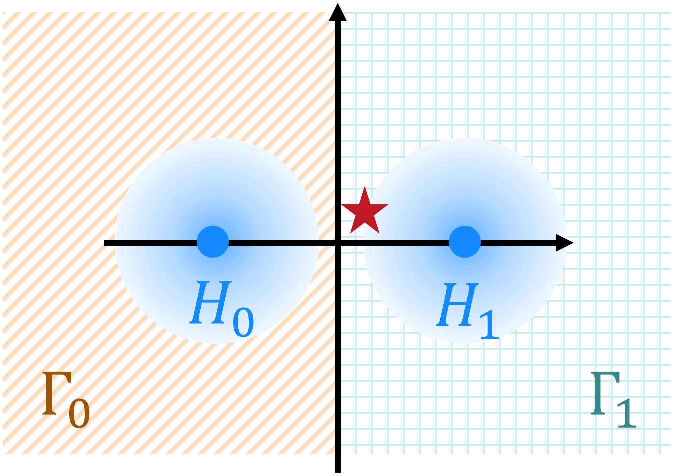
Decision Rule

M possible hypotheses

"Best" guess based on observation

Typical: minimize the probability of error

Hypothesis Testing



$H_0: Y \sim \mathcal{N}(-a, v^2)$

$H_1: Y \sim \mathcal{N}(a, v^2)$

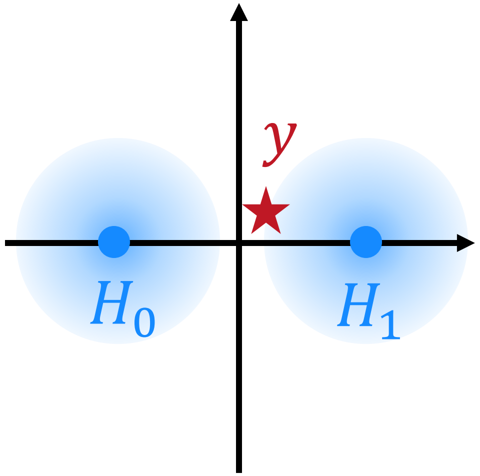
$$\delta(y) = \begin{cases} 0, y \le 0 \\ 1, y > 0 \end{cases}$$

What if $\pi_0 = 1$?

H_0 is true, always!

Hypotheses	$H_0, H_1, \cdots, H_{M-1}$
Observation	$Y \in \Gamma$
Conditional densities	$p(y\|i)$, $i = 0, 1, \cdots, M-1$
Prior probabilities	$\pi_i = P[H_i]$, $i = 0, 1, \cdots, M-1$, $\sum_{i=0}^{M-1} \pi_i = 1$
Decision rule	$\delta: \Gamma \to \{0, 1, \cdots, M-1\}$
Decision Regions	$\Gamma_i = \{y \in \Gamma: \delta(y) = i\}$, $i = 0, 1, \cdots, M-1$

Maximum Likelihood (ML) Decision Rule



$H_0: Y \sim \mathcal{N}(-a, v^2)$

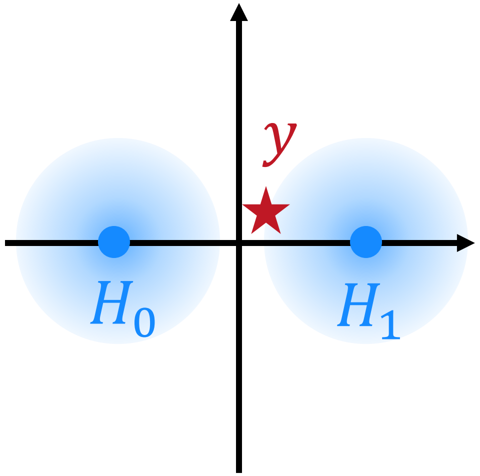
$H_1: Y \sim \mathcal{N}(a, v^2)$

$$\begin{aligned}\delta_{ML}(y) &= \arg\max_{0 \le i \le M-1} p(y \mid i) \\ &= \arg\max_{0 \le i \le M-1} \log p(y \mid i)\end{aligned}$$

This makes sense, right?

But what if the transmitter always sends bit 0?

Maximum A Posteriori Probability (MAP) Rule



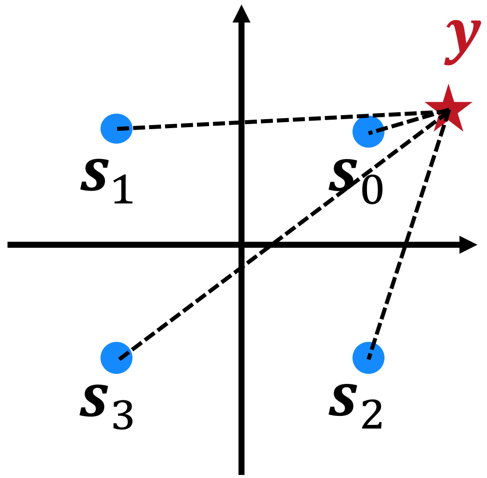
$$\begin{aligned}\delta_{MAP}(y) &= \arg\max_{0\le i\le M-1} P[H_i \mid Y = y] \\ &= \arg\max_{0\le i\le M-1} \pi_i\, p(y \mid i) \\ &= \arg\max_{0\le i\le M-1} \log \pi_i + \log p(y \mid i)\end{aligned}$$

A Posteriori Probability

$$P[H_i \mid Y = y] = \frac{p(y \mid i)\, P[H_i]}{p(y)} = \frac{\pi_i\, p(y \mid i)}{p(y)}, \qquad i = 0, 1, \cdots, M-1$$

The MAP rule reduces to the ML rule for equal priors

Optimal Demodulation in Discrete Time AWGN



$$H_i: \quad \boldsymbol{Y} = \boldsymbol{s}_i + \boldsymbol{N}$$

$$i = 0, 1, \cdots, M-1$$

$$\boldsymbol{N} \sim \mathcal{N}(0, \sigma^2 \boldsymbol{I})$$

ML

$$\delta_{ML}(y) = \arg \min_{0 \le i \le M-1} \boxed{\|\boldsymbol{y} - \boldsymbol{s}_i\|^2}$$

Minimum distance rule

Hint:

$$\mathcal{N}(\mu, \sigma^2) \sim \frac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{-(x-\mu)^2}{2\sigma^2}}$$

MAP

$\log_2, \log_e, \log_{10}$?

$$\delta_{MAP}(y) = \arg \min_{0 \le i \le M-1} \|\boldsymbol{y} - \boldsymbol{s}_i\|^2 - \boxed{2\sigma^2 \log \pi_i}$$

Reflecting prior knowledge

Dominant when SNR is low (large σ)

$\Longrightarrow$ Rely more on prior knowledge at low SNR

Binary Hypothesis Testing & Likelihood Ratio

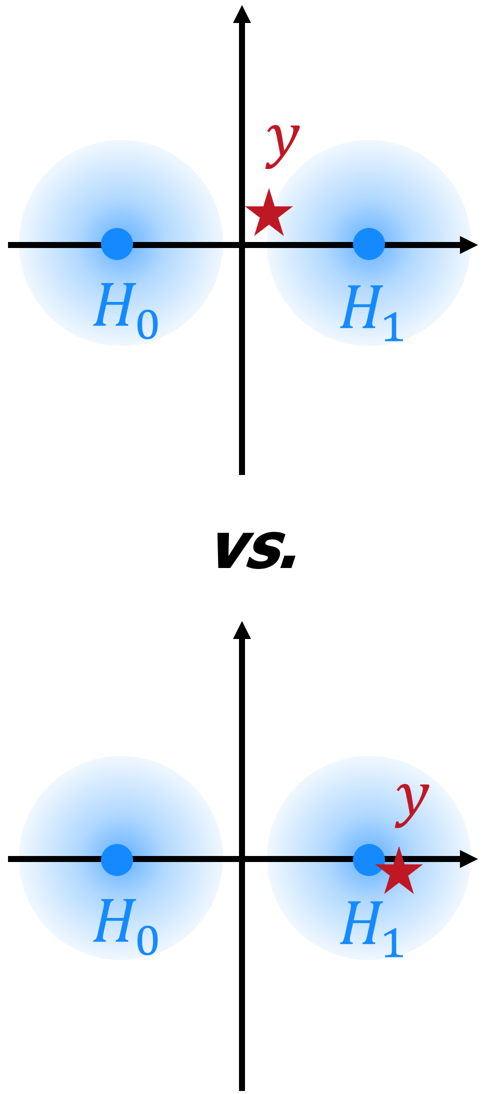
When only two hypotheses:

Likelihood Ratio $L(y) = \dfrac{p(y \mid 1)}{p(y \mid 0)}$

ML $\quad p(y \mid 1) \underset{H_0}{\overset{H_1}{\gtrless}} p(y \mid 0) \quad \Rightarrow \quad \dfrac{p(y \mid 1)}{p(y \mid 0)} \underset{H_0}{\overset{H_1}{\gtrless}} 1 \quad \Rightarrow \quad L(y) \underset{H_0}{\overset{H_1}{\gtrless}} 1$

MAP $\quad \pi_1 \, p(y \mid 1) \underset{H_0}{\overset{H_1}{\gtrless}} \pi_0 \, p(y \mid 0) \quad \Rightarrow \quad \dfrac{p(y \mid 1)}{p(y \mid 0)} \underset{H_0}{\overset{H_1}{\gtrless}} \dfrac{\pi_0}{\pi_1} \quad \Rightarrow \quad L(y) \underset{H_0}{\overset{H_1}{\gtrless}} \dfrac{\pi_0}{\pi_1}$

Soft Decisions



Both demodulated as bit 1

One result is more confident than the other

Soft Decision

$$\pi_i(y) = P[H_i \mid Y = y] = \frac{p(y \mid i)\, P[H_i]}{p(y)}$$

$$= \frac{\pi_i\, p(y \mid i)}{\sum_{j=0}^{M-1} \pi_j\, p(y \mid j)}$$

Convey reliability information

Can be used at a higher layer, e.g., error correction

References

- Madhow, Upamanyu. *Introduction to communication systems*. Cambridge University Press, 2014. [Unofficial version on UC Santa Barbara Website]
  - Chap 6

- Joachim Speidel. *Introduction to digital communications*. Springer Nature, 2021. [NTU Library Link]
  - Chap. 3

- Andreas F. Molisch, *Wireless communications*. Vol. 34. John Wiley & Sons, 2012. [NTU Library Link]
  - Chap. 12

Paper Debate and Review

Announce Debate Teams

Acknowledgment

Prof. Edward W. Knightly

Why Paper Debate?

- Why read papers?
  - Broaden your horizon in the field of wireless communications & networks
  - Get to know the frontier of research
  - See examples of high-quality research
- Why debate?
  - Critical thinking skills
(YOU decide whether the design & results make sense. Not to simply accept as is.)
  - Think from different perspectives
  - Practice to make persuasive arguments
- When will you need these skills?
  - MS defense

Debate Format

20 minutes	Defense Team
10 minutes	Offense Team
5 minutes	Preparation time
10 minutes	Follow up arguments
5 minutes	Questions and comments from class

Timing will be strictly enforced!

Think Tank

- For the rest of the class who are not debating, you can choose to be the “think tank” of either side.

- The debate teams can consult with their “think thank” during the preparation time

Defense Team - Guidelines

Goal: Assess the contribution of a piece of work, anticipate likely attacks, and defend it from criticism.

- Beyond simply a paper summary
- Discuss the work as if it were YOUR thesis defense
- Make a compelling case why the contribution is significant and Ph.D.-worthy
- Anticipate likely attacks and defend preemptively
- Should NOT critique the work other than to try to preempt attacks from the offense (e.g., by explicitly limiting the scope of the contribution)
- Be aware of the prior work – you know the offense team will get to you

Defense Team – What Should Be Included

Quick Summary of the Paper

Clear problem definition and importance, why this problem is PhD level, why prior work is not enough, novelty of the proposed approach, significant results and their implications

What is new

Knowledge, methods, experiments, insights, techniques, …

Provide the context

Discuss prior work and differentiate from it

Impact

Contribution, potential impact on the research community, industry, and standards.

Offense Team - Guidelines

Goal: critical analysis of research

- Avoid unsubstantiated or conclusory criticism

❌ "The results are obvious."

❌ "The proposed system is impractical."

- First-person statements are not allowed

❌ "I think it would be better if the authors had …"

- Should not pose questions or hypotheticals

❌ "Will this work for mobile clients?"

❌ "Why didn't they consider the case of N = 2?"

Offense Team - Guidelines

Goal: critical analysis of research

- Focus on well-reasoned, factual, and justified analysis based on prior work
  - "Even if this problem is completely solved, the throughput can only improve by 2%."
- Criticism should be made as an authoritative and direct statement
  - "To convincingly demonstrate X, the authors should have designed an experiment in which they varied Y."
  - "The authors failed to differentiate their approach from a nearly identical and uncited method in [Z]."
  - "The authors should have considered the case of N=2, because it is critical to establish …"

Offense Team – Common Critiques

- Lack of novelty
- Unaddressed issues
- Lack of impact
- Close similarities to prior work
- Inappropriateness of the problem formulation
- The proposed approach fails to address the defined problem
- Overstating, misleading
- Flaws in methodology
- …

Consolidate to
<u>Top 3 Arguments</u>
in Conclusion

To Both Teams

- Be prepared, and be present
- Remember to take notes and prepare your response when the other team speaks
- Find out flaws in others' arguments on the fly

Preparation meeting with Chia-Yi

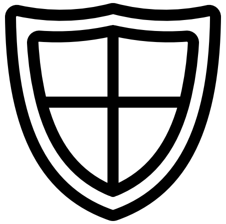
- The debate teams must meet with me one week before the debate
  - Be prepared to give a summary of the paper (All members should have read the paper)
  - Discuss advanced concepts you don’t quite understand
  - Discuss likely attacks and strategies to address them
  - Discuss how to find prior work that challenges the debate paper
  - Discuss arguments
- Separate meeting slots for the two teams
  - I will try to keep secrets for both sides :)

Grading: Presenters

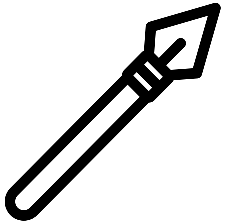
Time control: 20%

- 1-minute grace period
- 10% off for every additional minute afterward
- It's ok to not use up all your time

Content: 40%



Convey the contribution in an organized, coherent, and compelling way



The more insightful and less obvious the criticisms, the more points

Must include prior works in your argument

Response: 20%

- Address challenges raised from the other side

Student evaluation: 20%

- Effectiveness/persuasiveness of arguments (scale 1~5)

For the Rest of the Class: Paper Review Form

Paper summary: 30%

- Problem
- Related work
- Methodology
- Result/Contribution

Analysis of one result figure: 30%

- Problem/Hypothesis
- Methodology
- Result
- Analysis

Strengths and Weaknesses: 30%

- At least one strength
- At least one weakness
- Your best points

Recommendation: 5%

- Reject
- Weak reject
- Borderline
- Weak accept
- Strong accept

AI Tools Usage: 5%

AI Tools Policy

- Use it to help understand the paper.
- Don’t use it to write the review form.

Grading: Paper review form

Paper s **knesses: 30%**

- Probler
- Relatec
- Methoc
- Result/

5%

Analysi

- Probler
- Methoc
- Result
- Analysi

Communication Systems Lab | Fall 2025 | National Taiwan University

Paper Review Form

English is strongly recommended but not required.

1. Paper summary. (30%)

Please write a paragraph (max 200 words) summarizing the paper with the following components:

- **Problem**: What is the problem this paper aims to address?
- **Related work**: What does prior work lack in solving the problem?
- **Methodology**: What is the proposed approach? What techniques do they use?
- **Result/Contribution**: What are the results? What have the authors demonstrated?

Try your best to make the summary easy to understand for someone like you who has a general engineering background but does not have expertise in the field.

	7.5	**4**	**0**
Problem **Related work** **Methodology** **Result/Contribution**	Complete and correct.	1) Incomplete, 2) Only partially correct, or 3) Too much jargon impedes understanding.	1) Missing, 2) Completely incorrect, or 3) Purely AI-generated.

Exceeding word limit, -10 points.

Let’s check out the paper review form.

Paper Summary – AI-Generated vs. Chia-Yi's Version

Paper Summary of MobiCom'25 accepted paper titled
"Poison to Cure: Privacy-preserving Wi-Fi Multi-User Sensing via Data Poisoning"

Can you tell which one is AI-generated (in this case, Gemini 2.5 Flash)?

This paper addresses the problem of privacy breaches caused by Wi-Fi human sensing. While existing methods like signal obfuscation and adversarial perturbations exist, they require hardware modifications and lack semantic-level control. The proposed methodology, called Poison2Cure, is a data-poisoning framework that degrades Wi-Fi sensing accuracy for private activities while preserving it for regular ones. The innovation lies in strategically poisoning the training data during the neural model's fine-tuning process. The authors tackle challenges like confidential neural models and data cleansing by using surrogate models and enforcing frequency and power constraints on the poisoned data. The results show that Poison2Cure reduces the accuracy for private activities by over 76% while largely maintaining the accuracy for regular activities. The main contribution is a fully hardware-compatible framework that enables semantic-level privacy for Wi-Fi sensing systems.

This paper aims to preserve users' privacy in Wi-Fi sensing applications. The system model considers the Wi-Fi AP to use a neural network to classify users' activities (walking, hand-shaking, etc.), among which some activities are deemed private by the user. The authors propose to provide the AP with a fine-tuning (FT) dataset in which CSI data is first treated ("poisoned" as they call it) so that the classification accuracy increases for regular activities but decreases for user-defined private activities. Their insight is that the added "poison" should make the gradient of the user's loss (account for both regular and private activities) and the AP's loss aligned. Their experimental result shows that the proposed poison effectively suppresses the classification accuracy for the user-defined private activities, with minimum accuracy reduction for the regular activities. They further show that the poison is effective even when AP's model is not fully opened to the user, and the poison is resilient to AP's data cleansing operations, including outlier removal and low-pass filtering.

Paper Summary – Real People Provide Perspectives

Emphasis on Different Aspects.

Use words not necessarily in the paper to better reflect your interpretation:
Fine-tuning dataset ➔ Calibration data

The authors of this paper propose a novel framework named Poison2Cure to endow Wi-Fi human sensing systems with semantic-level user privacy preservation. Poison2Cure is featured by an innovative design that lets a user poison its calibration data sent to the AP, resulting in the neural model of the AP misclassifying private user activities while accurately recognizing other ones. The paper first demonstrates why user calibration is necessary for multi-user Wi-Fi sensing systems. Then, to tackle the challenge of poisoning high-dimensional CSI data, the authors propose a resource-efficient algorithm to align the neural parameter calibration towards the user's privacy preservation goal. Moreover, they extend it to handle practical conditions where partial information of the neural model is unknown or the CSI data undergo cleansing. By implementing the system with commodity Wi-Fi devices and conducting practical experiments on it, the effectiveness of Poison2Cure is validated.

This paper aims to preserve users' privacy in Wi-Fi sensing applications. The system model considers the Wi-Fi AP to use a neural network to classify users' activities (walking, hand-shaking, etc.), among which some activities are deemed private by the user. The authors propose to provide the AP with a fine-tuning (FT) dataset in which CSI data is first treated ("poisoned" as they call it) so that the classification accuracy increases for regular activities but decreases for user-defined private activities. Their insight is that the added "poison" should make the gradient of the user's loss (account for both regular and private activities) and the AP's loss aligned. Their experimental result shows that the proposed poison effectively suppresses the classification accuracy for the user-defined private activities, with minimum accuracy reduction for the regular activities. They further show that the poison is effective even when AP's model is not fully opened to the user, and the poison is resilient to AP's data cleansing operations, including outlier removal and low-pass filtering.

Example Grading of Paper Summary

Even paper summaries from professionals are not perfect!

Missing related work -7.5

The authors of this paper propose a novel framework named Poison2Cure to endow Wi-Fi human sensing systems with semantic-level user privacy preservation. Poison2Cure is featured by an innovative design that lets a user poison its calibration data sent to the AP, resulting in the neural model of the AP misclassifying private user activities while accurately recognizing other ones. The paper first demonstrates why user calibration is necessary for multi-user Wi-Fi sensing systems. Then, to tackle the challenge of poisoning high-dimensional CSI data, the authors propose a resource-efficient algorithm to align the neural parameter calibration towards the user's privacy preservation goal. Moreover, they extend it to handle practical conditions where partial information of the neural model is unknown or the CSI data undergo cleansing. By implementing the system with commodity Wi-Fi devices and conducting practical experiments on it, the effectiveness of Poison2Cure is validated.

Missing related work -7.5

This paper aims to preserve users' privacy in Wi-Fi sensing applications. The system model considers the Wi-Fi AP to use a neural network to classify users' activities (walking, hand-shaking, etc.), among which some activities are deemed private by the user. The authors propose to provide the AP with a fine-tuning (FT) dataset in which CSI data is first treated ("poisoned" as they call it) so that the classification accuracy increases for regular activities but decreases for user-defined private activities. Their insight is that the added "poison" should make the gradient of the user's loss (account for both regular and private activities) and the AP's loss aligned. Their experimental result shows that the proposed poison effectively suppresses the classification accuracy for the user-defined private activities, with minimum accuracy reduction for the regular activities. They further show that the poison is effective even when AP's model is not fully opened to the user, and the poison is resilient to AP's data cleansing operations, including outlier removal and low-pass filtering.

Paper Reading Tips - 1

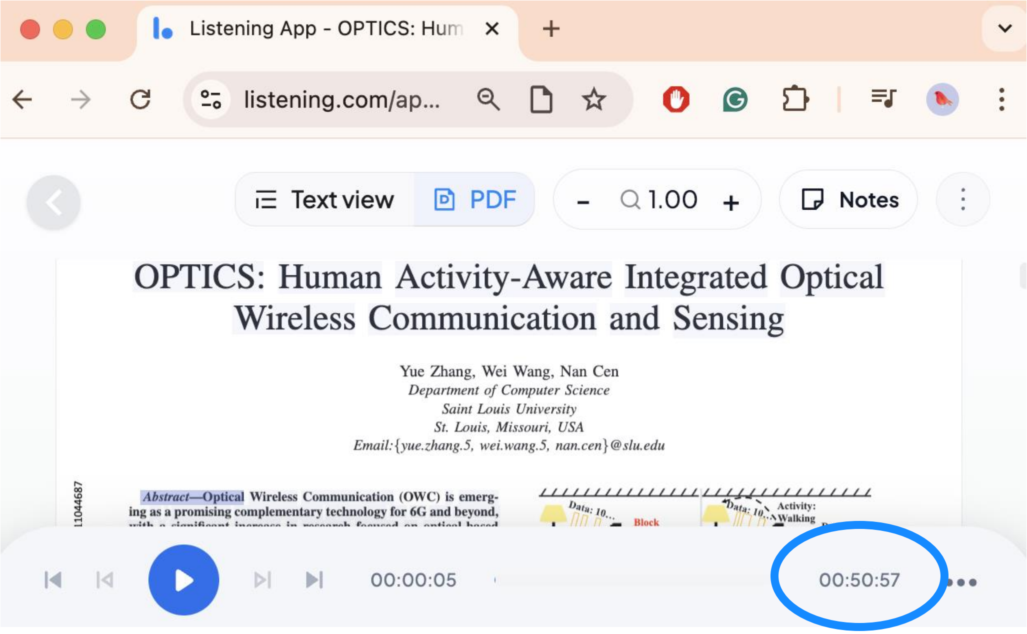
1. **Know your purpose**
   - Deep dive? Get an overview? Interested in system model or methodology (certain aspects)?
   - Your purpose determines how much time & effort you spend on a paper.
2. **Top-down**
   - Abstract & Conclusion → paper structure, figures, and tables
   - Before committing to reading, first imagine what would/should be discussed.
3. **Be critical**
   - Maintain your own line of story: The authors tell the story one way, but you should turn it into your version and check if the logic works out.
   - Remain skeptical until you are convinced: Papers are not necessarily correct!
   - Advantages & weaknesses: Give credit to what has been achieved, while being aware of the limitations.

Paper Reading Tips - 2

4. **Remember to check basic information**
    - Who (which team) wrote the paper? The same team may have follow-up work.
    - When was it published? Recent or not?
    - Which conference or journal? This can be a proxy for credibility.
5. **Always take note**
    - Notice things that differ from what you expect and note them down.
    - Your notes help you recall your memories.
6. **Additional resources**
    - Check author's or conference websites for slides or presentation recordings

How much time for reading one paper?

If you read aloud a 9-page double-column paper from the first word to the last, how long does it take?



Does that mean you should spend roughly one hour reading this paper?

Yes and No.

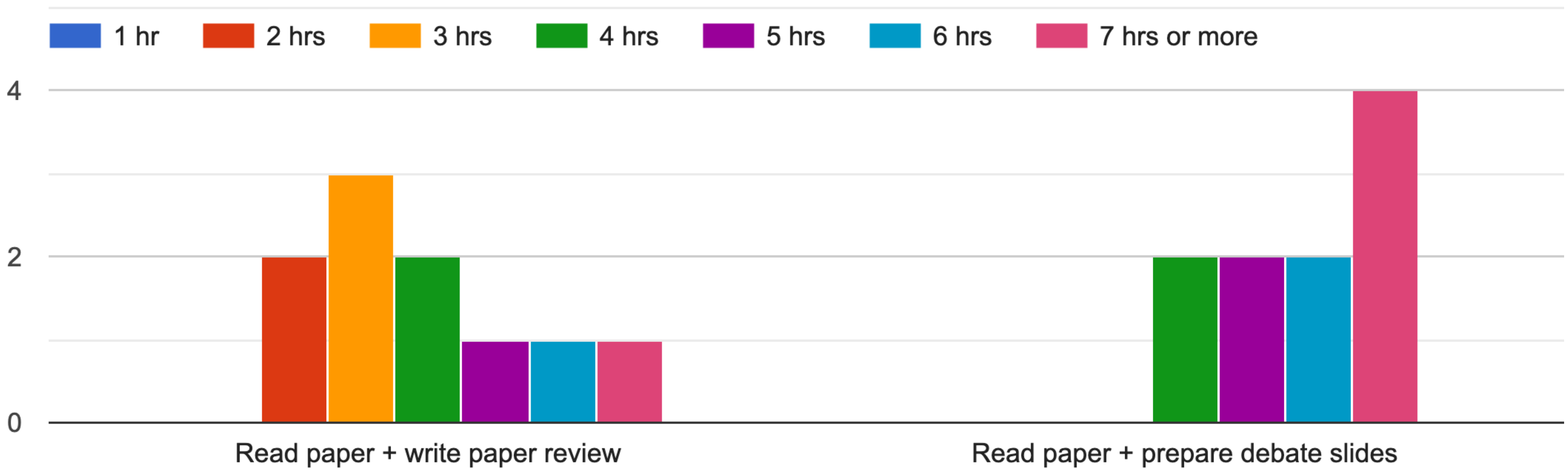
Yes, if you simply want to be done with the review form.

No, if you read more carefully and learn new things along the way.

It is common to spend 3+ hours on a paper, especially when the area is new!

113-2 Survey on paper reading time

How much time did you spend on paper review or debate preparation ?



Tips for searching related works

- Find others' opinions on the paper

RF-Egg: An RF Solution for Fine-Grained Multi-Target and Multi-Task Egg Incubation Sensing
Z Sun, T Ni, Y Chen, D Duan, K Liu, W Xu
Proceedings of the 30th Annual International Conference on Mobile Computing …, 2024 • dl.acm.org

Eggs and chickens serve as crucial anim
scale breeding egg incubation an essenti
vision-based and sensor-based methods
tasks under single-egg settings, which ha
multi-task sensing. In this paper, we prop
multi-target and multi-task egg incubatio

SHOW MORE

Save Cite **Cited by 4** Related articles

RF-Egg: An RF Solution for Fine-Grained Multi-Target and Multi-Task Egg Incubation Sensing

Search within citing articles

Towards ISAC-Empowered mmWave Radars by Capturing Modulated Vibrations [PDF] ieee.org
K Cui, Q Yang, L Shen, Y Zheng… - IEEE Transactions on …, 2024 - ieeexplore.ieee.org
Integrated Sensing and Communication (ISAC) has emerged as a promising technology for next-generation mobile networks. Towards ISAC, we develop mmRipple that empowers …
Save Cite Related articles All 2 versions

Towards Battery-Free Wireless Sensing via Radio-Frequency Energy Harvesting [PDF] arxiv.org
T Ni, Z Sun, M Han, G Lan, Y Xie, Z Li, T Gu… - arXiv preprint arXiv …, 2024 - arxiv.org
Diverse Wi-Fi-based wireless applications have been proposed, ranging from daily activity recognition to vital sign monitoring. Despite their remarkable sensing accuracy, the high …
Save Cite Related articles All 3 versions

- Find uncited prior work
  - One team found an important baseline that was (supposedly) intentionally left out in comparison!

Submission Time

Non-presenters

10am on the debate day

- Paper review form

Presenters

After the debate before midnight

- Slides
- List of contributions of each team member