POLITECNICO DI TORINO
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TIM

IoT Notifications: from disruption to benefit

Architectures for the future of notifications in the IoT

Supervisor(s)

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Presenter

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Research GOAL

Investigate the intelligence component in **Internet of Things (IoT)** architectures and applications: study, define, and prototype **intelligent distributed architectures** that may extract additional value and intelligent behaviors to some significant sample problems, representative of future IoT scenarios.

The **distribution and customization of notifications** in the IoT domain has been treated as an example of possible future IoT scenarios.

Notification Context: sample scenario

Source: https://iot.do/windstream-research-future-connected-home-community-2015-04

Notification Context: sample scenario

Date: 9th September 2018

Source: https://iot.do/windstream-research-future-connected-home-community-2015-04

Notification Context: sample scenario

Date: 9th September 2018

Time: 19.00

Source: https://iot.do/windstream-research-future-connected-home-community-2015-04

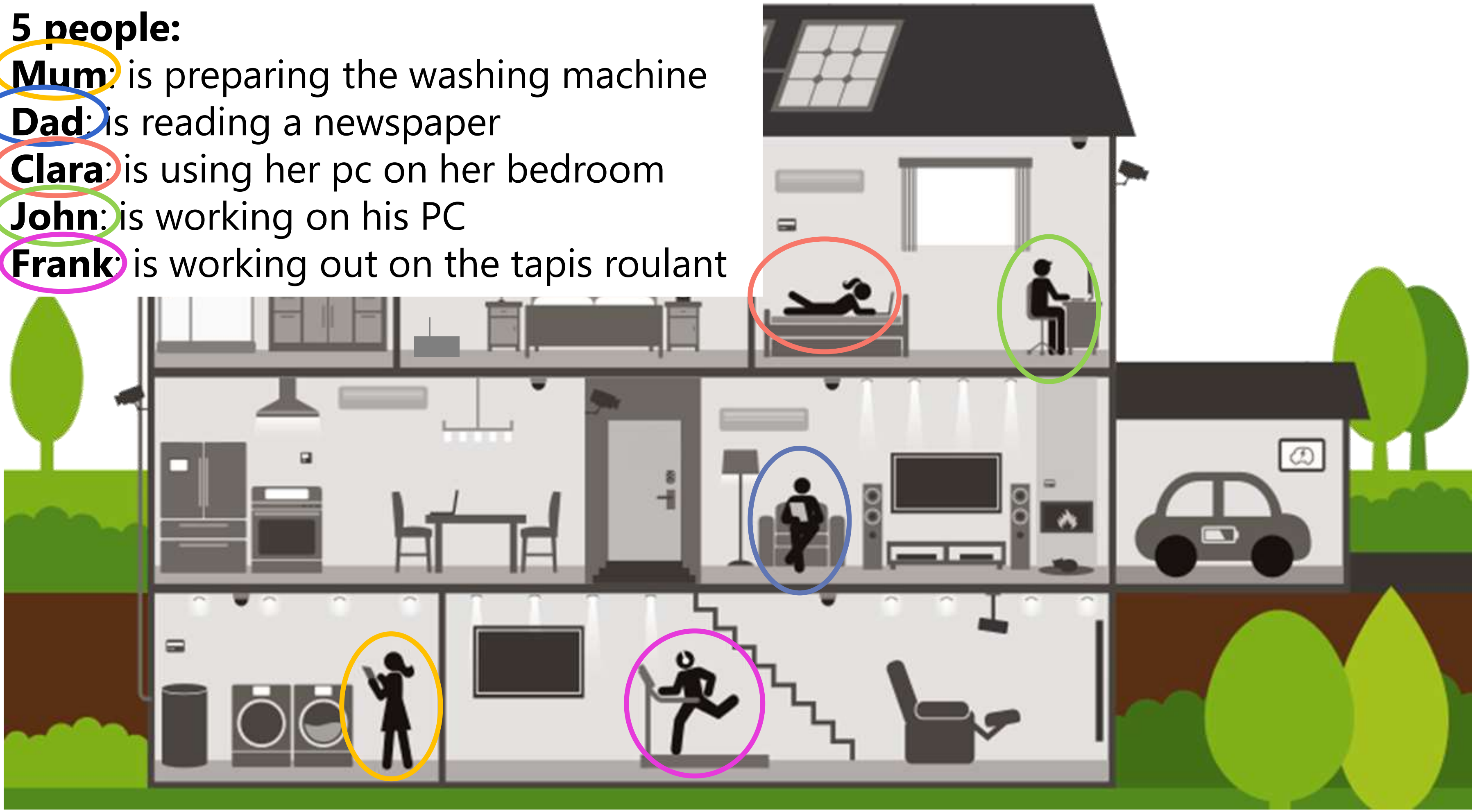
Notification Context: sample scenario

Date: 9th September 2018

Time: 19.00

5 people:

Mum: is preparing the washing machine
Dad: is reading a newspaper
Clara: is using her pc on her bedroom
John: is working on his PC
Frank: is working out on the tapis roulant



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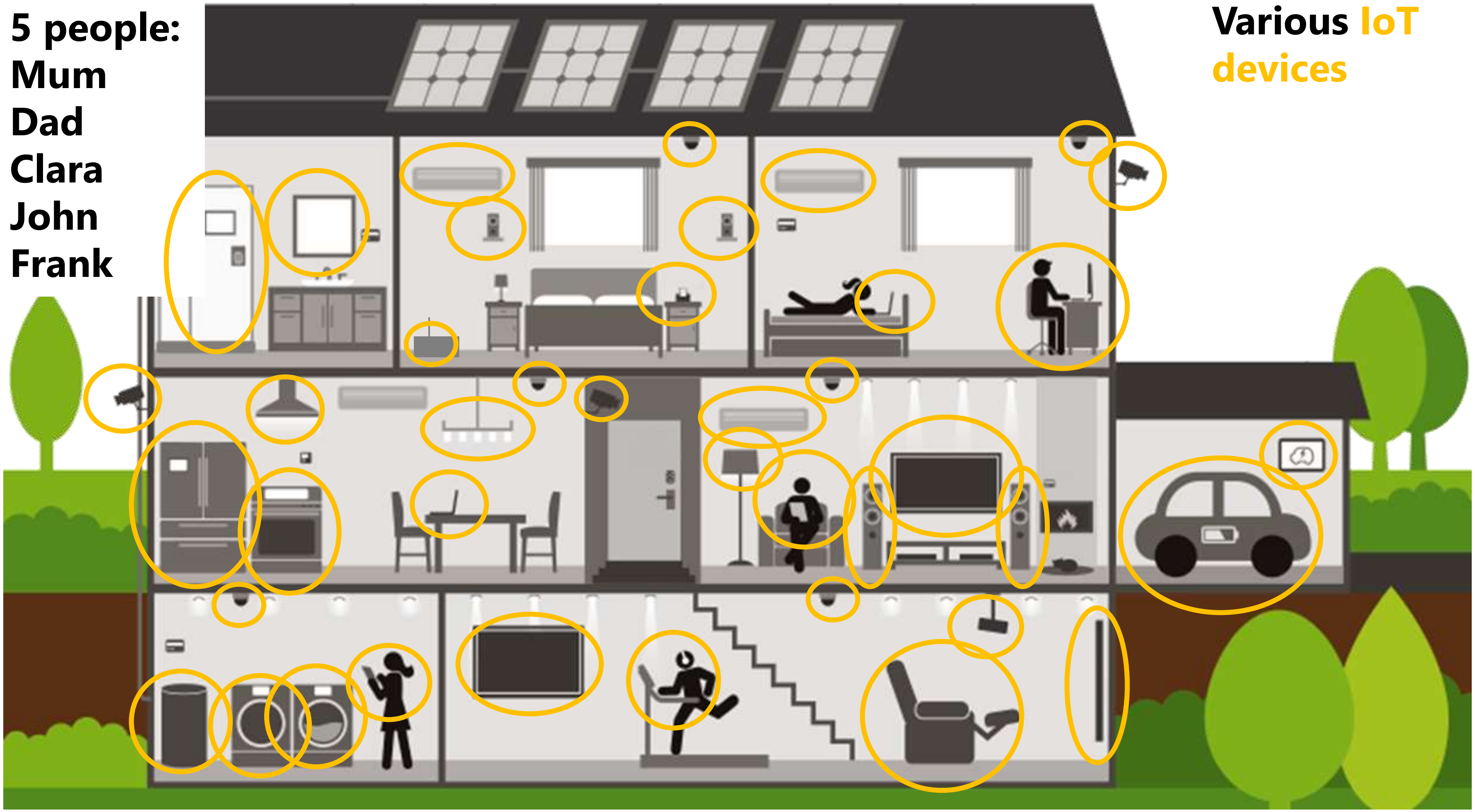
Various IoT devices



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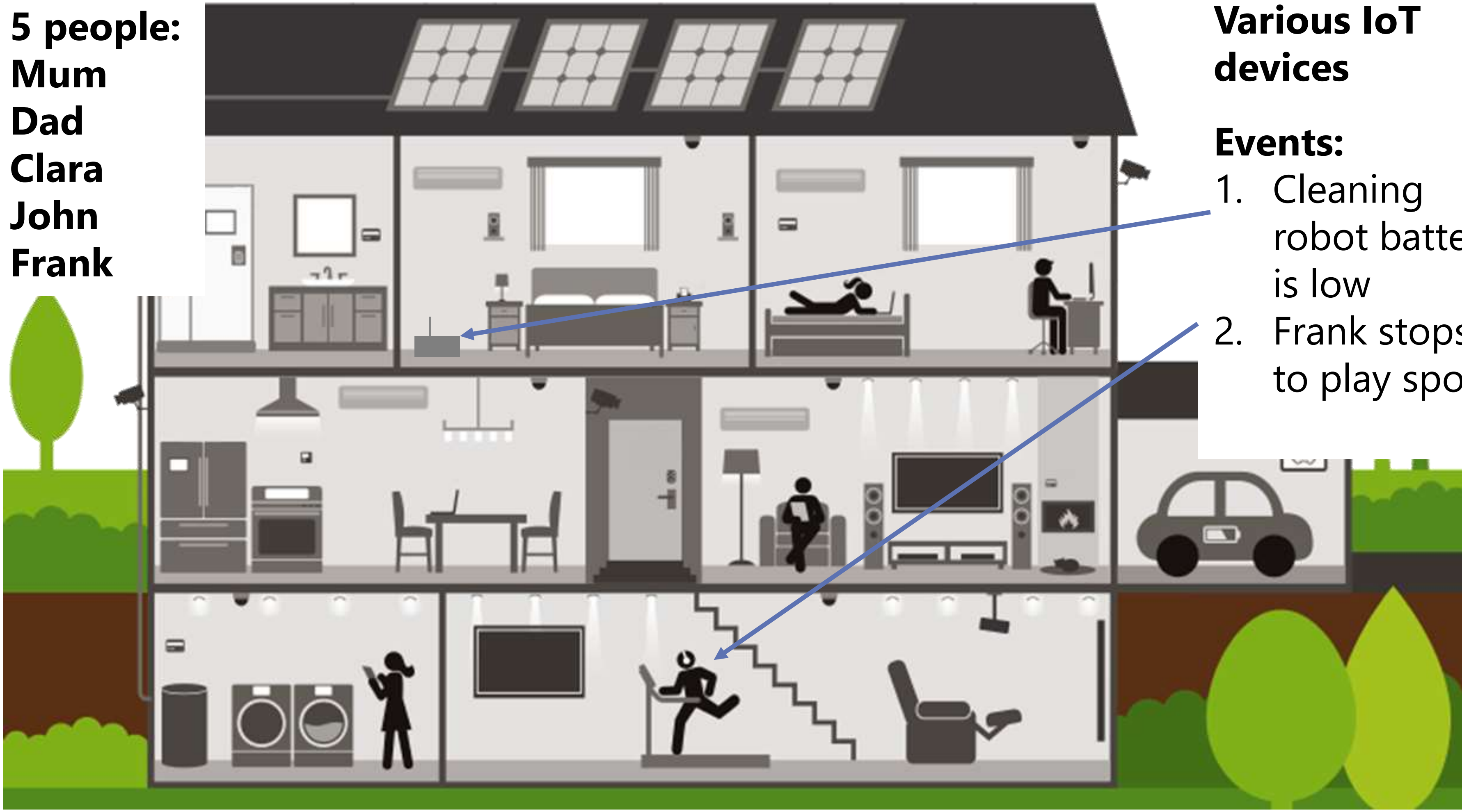

Various IoT devices

Events:

1. Cleaning robot battery is low
2. Frank stops to play sport

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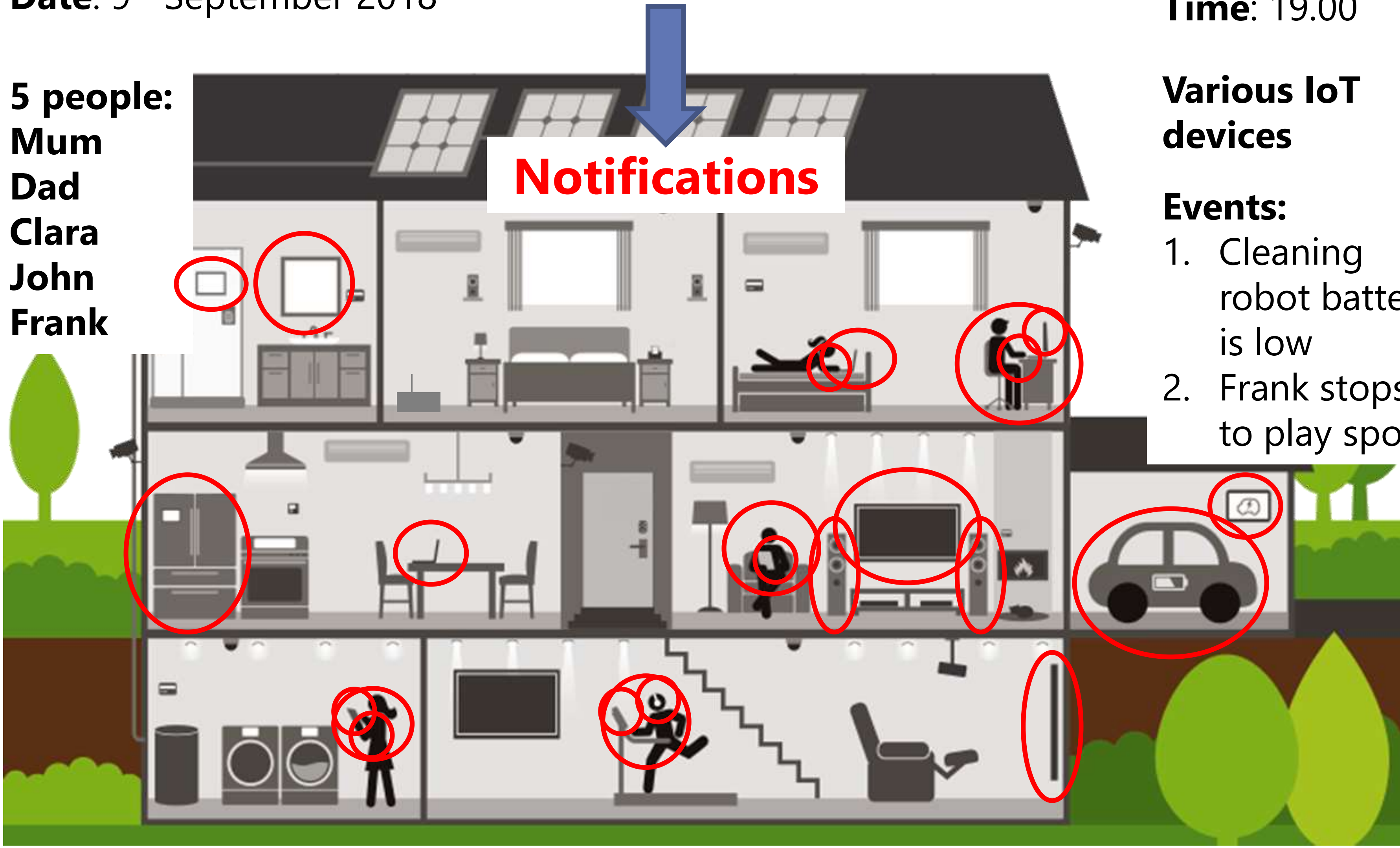

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Various IoT devices

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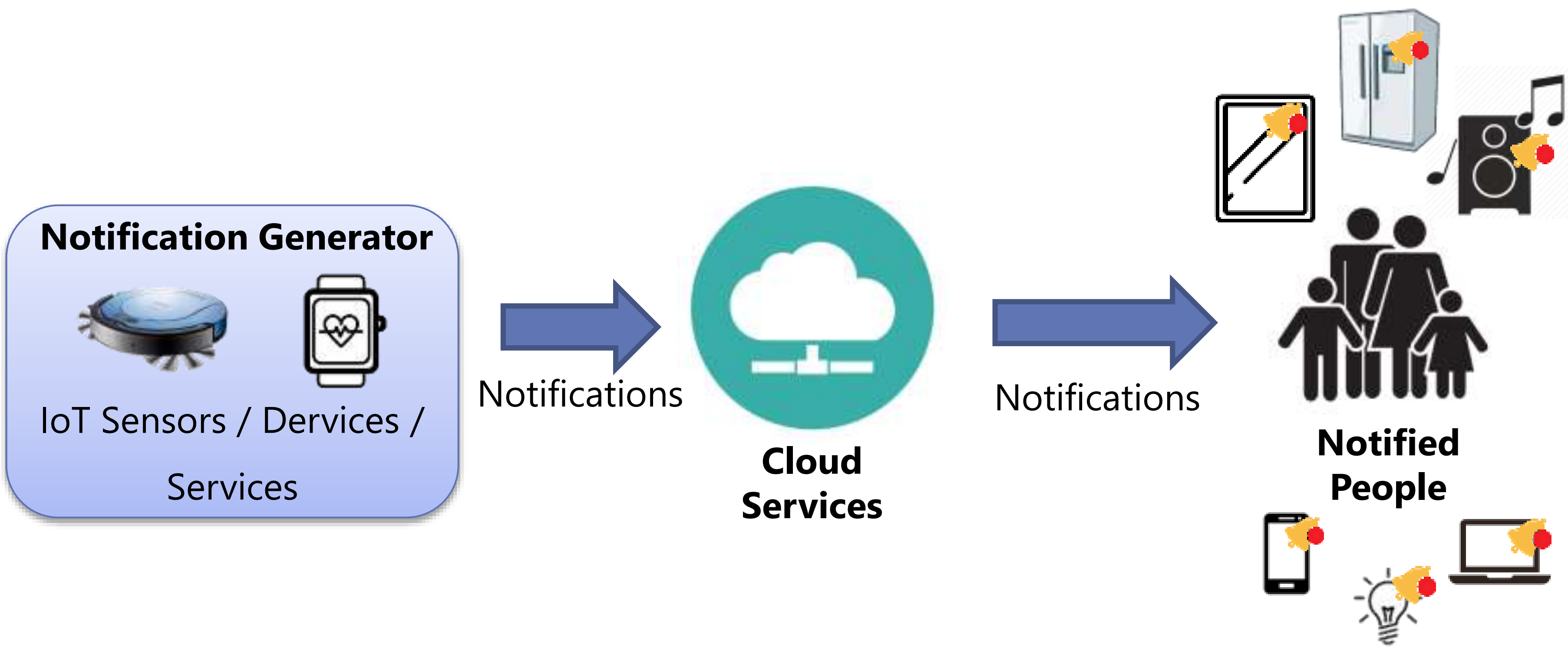
Main problem

Notifications could be disruptive:

- **Wrong moment**
- **Wrong device** on which the notification is shown
- **Wrong modality** (e.g., vibration instead of sound)
- **Wrong person**(s)
- **Repetitive** notifications
- Too many **simultaneous** notifications
- **…**

Notification Context: sample scenario

Simplified version (used as a reference)

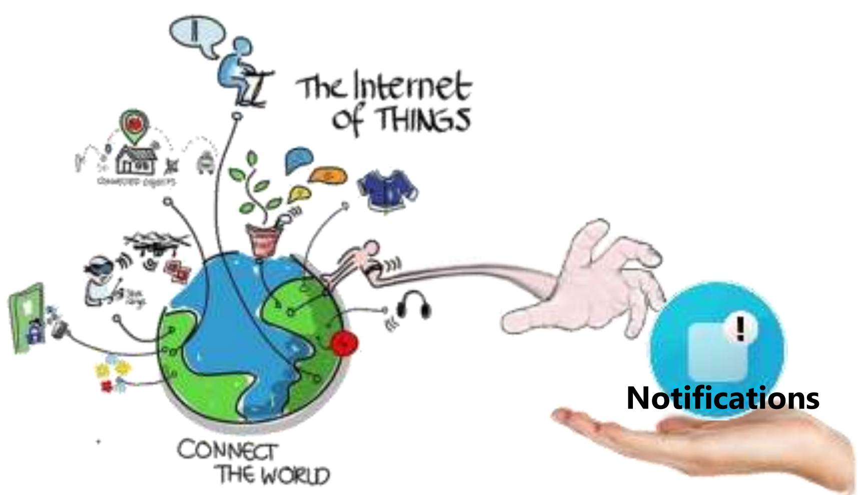


Main Research GOAL

Design and develop new **IoT architectures** to

a) **enhance** the **effect** of **IoT notifications** on **users experience**

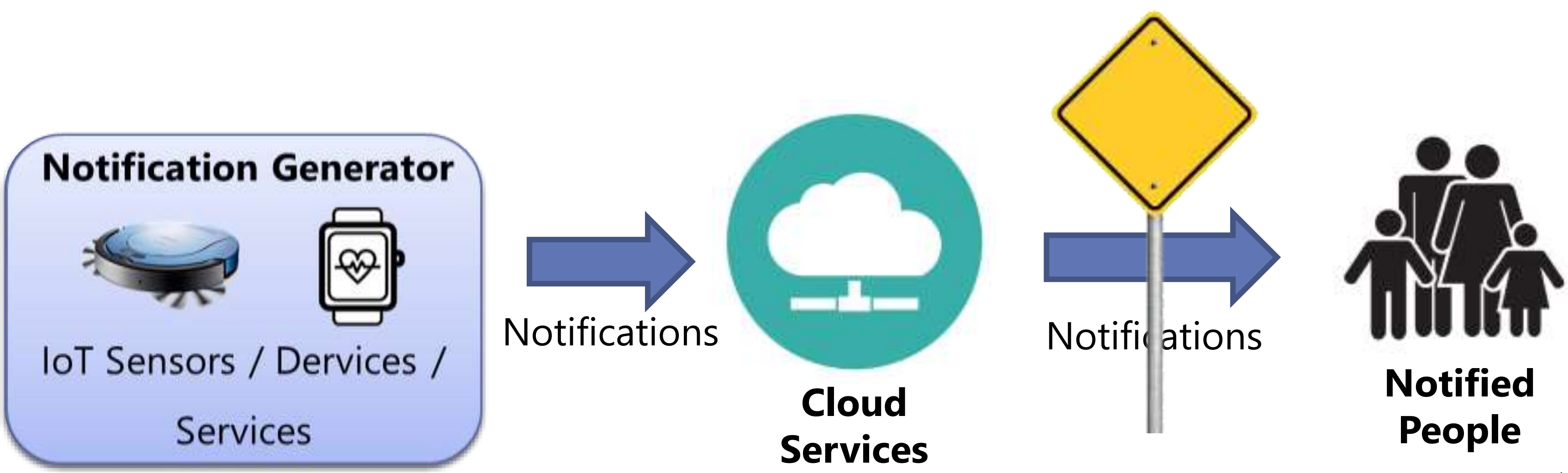
b) allow **developers** to **effectively exploit** the **notifications** improving their services, tools and applications.



Proposed solutions

Two different approaches are possible

1. At the **distribution level**: notifications are intercepted as soon as they arrive on the IoT devices and then systems decide if, when, and how to show them.



Proposed solutions

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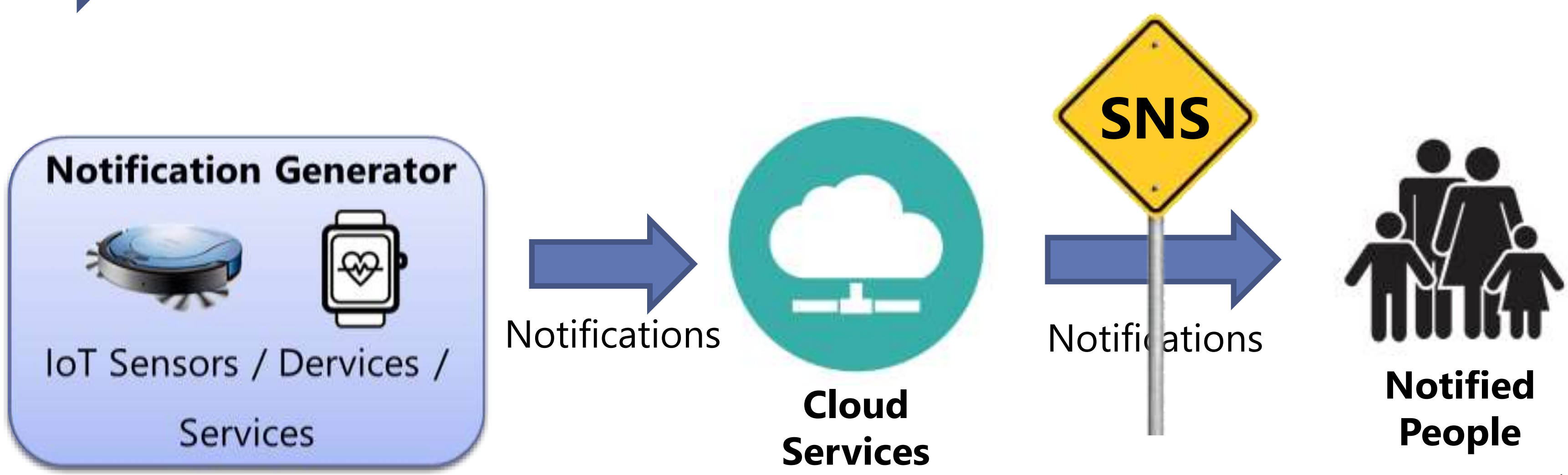
Solution: **Smart Notification System (SNS)**



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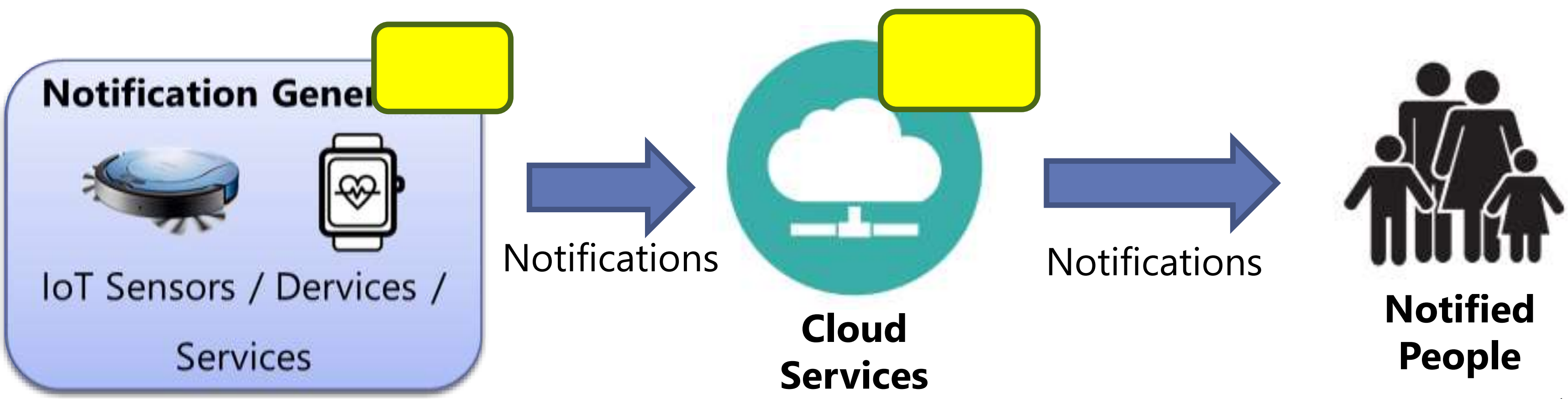
Two different approaches are possible

2. At the **design level**: notifications are designed with the aim of reducing user disruption.

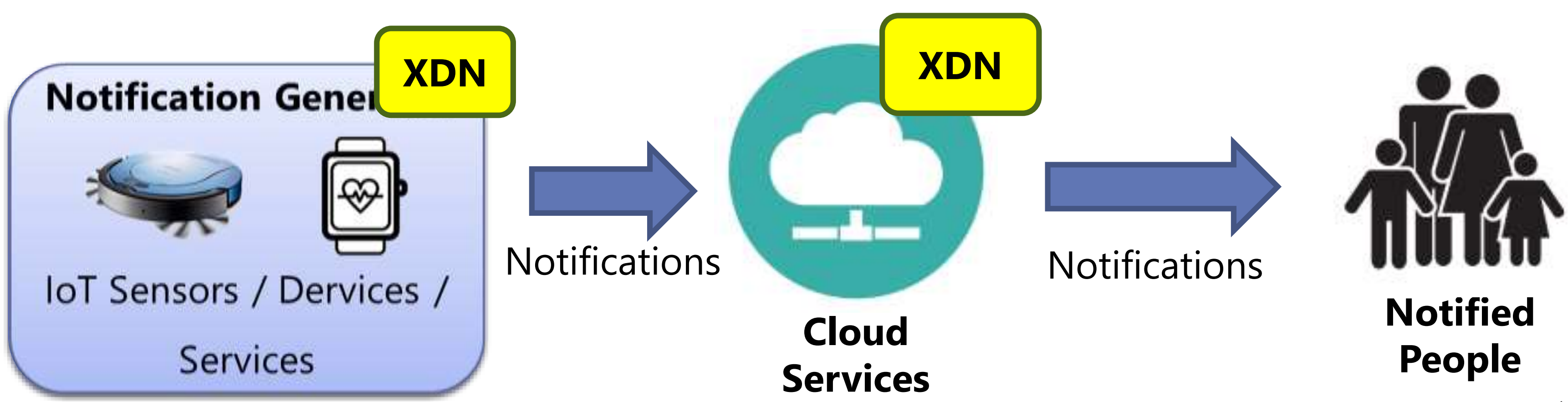


Proposed solutions

Two different approaches are possible

2. At the **design level**: notifications are designed with the aim of reducing user disruption.

→ Solution : **XDN (Cross Device Notifications) framework**



Smart Notification System (SNS)

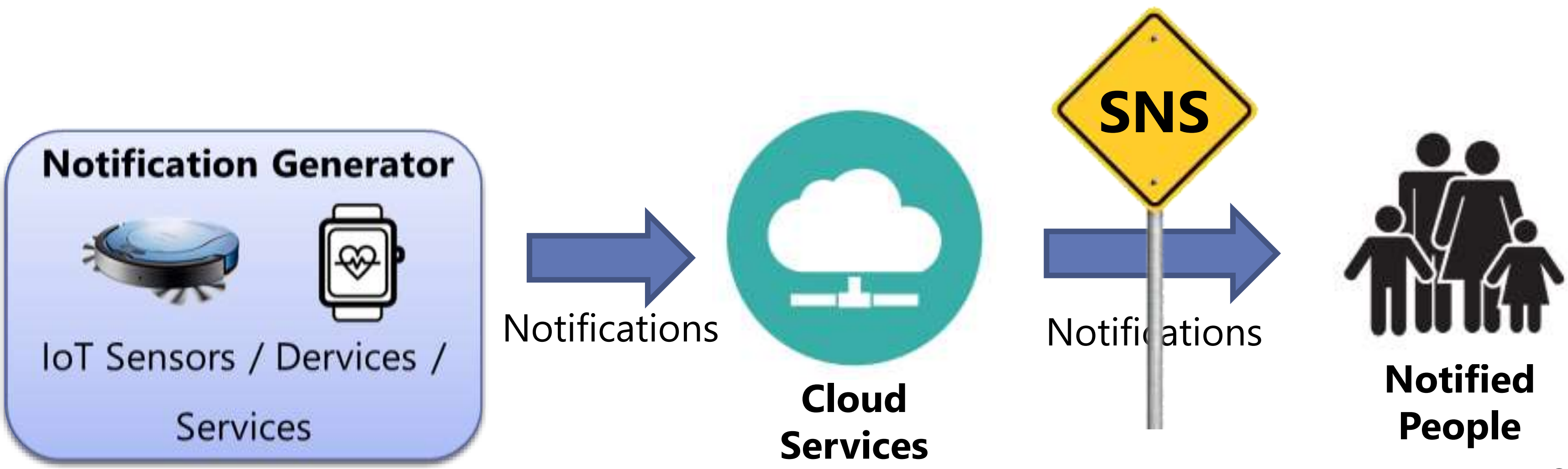
SNS

Smart Notification System (SNS): a modular architecture to deal with notifications at the distribution level.

It uses **machine learning algorithms** to manage **incoming notifications** according to **context awareness** and **users habits**.

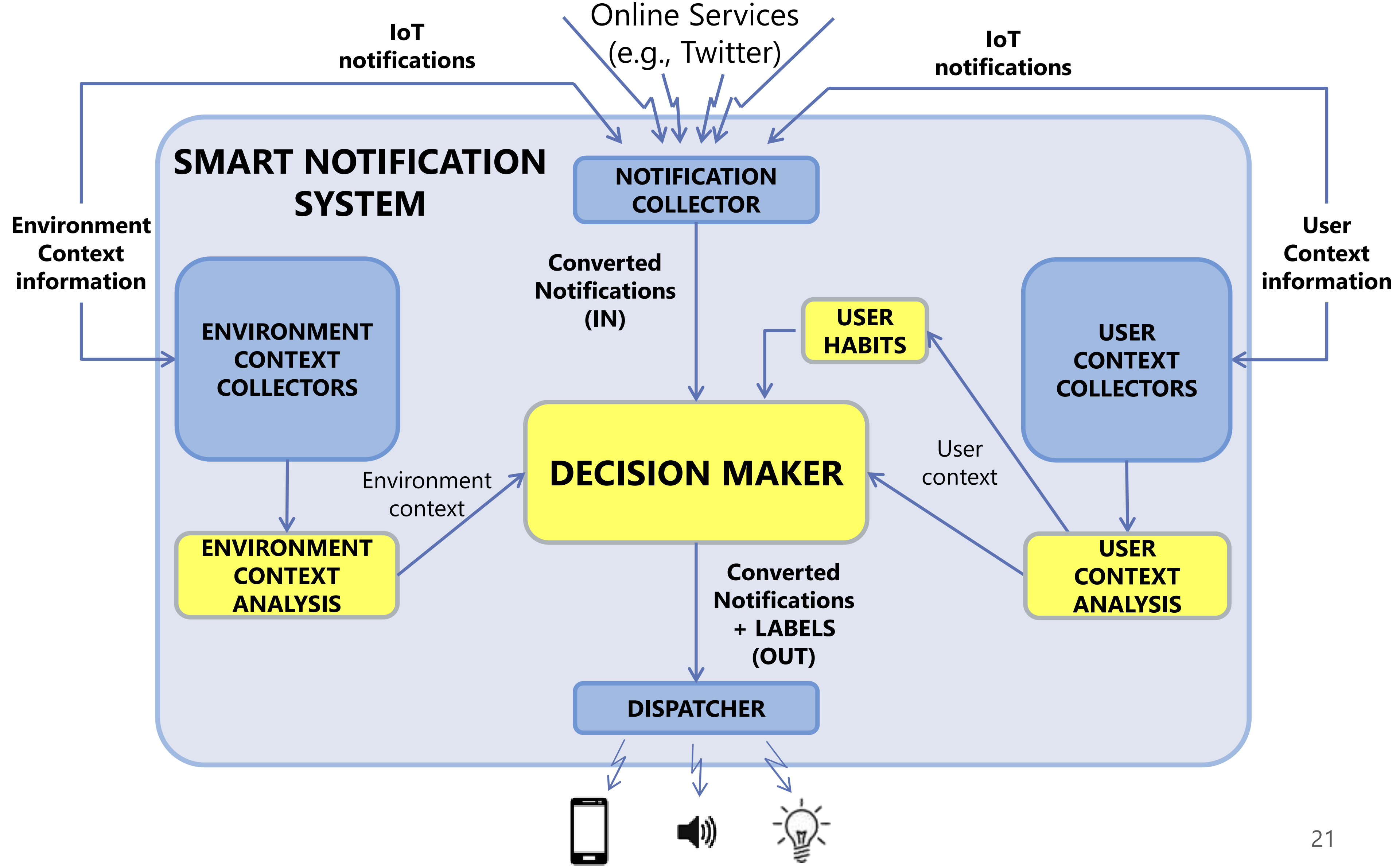
Our contributions:

1. **Architecture** design
2. **Prototypes** implementation of different architectural components



SNS: Architecture

Overview:



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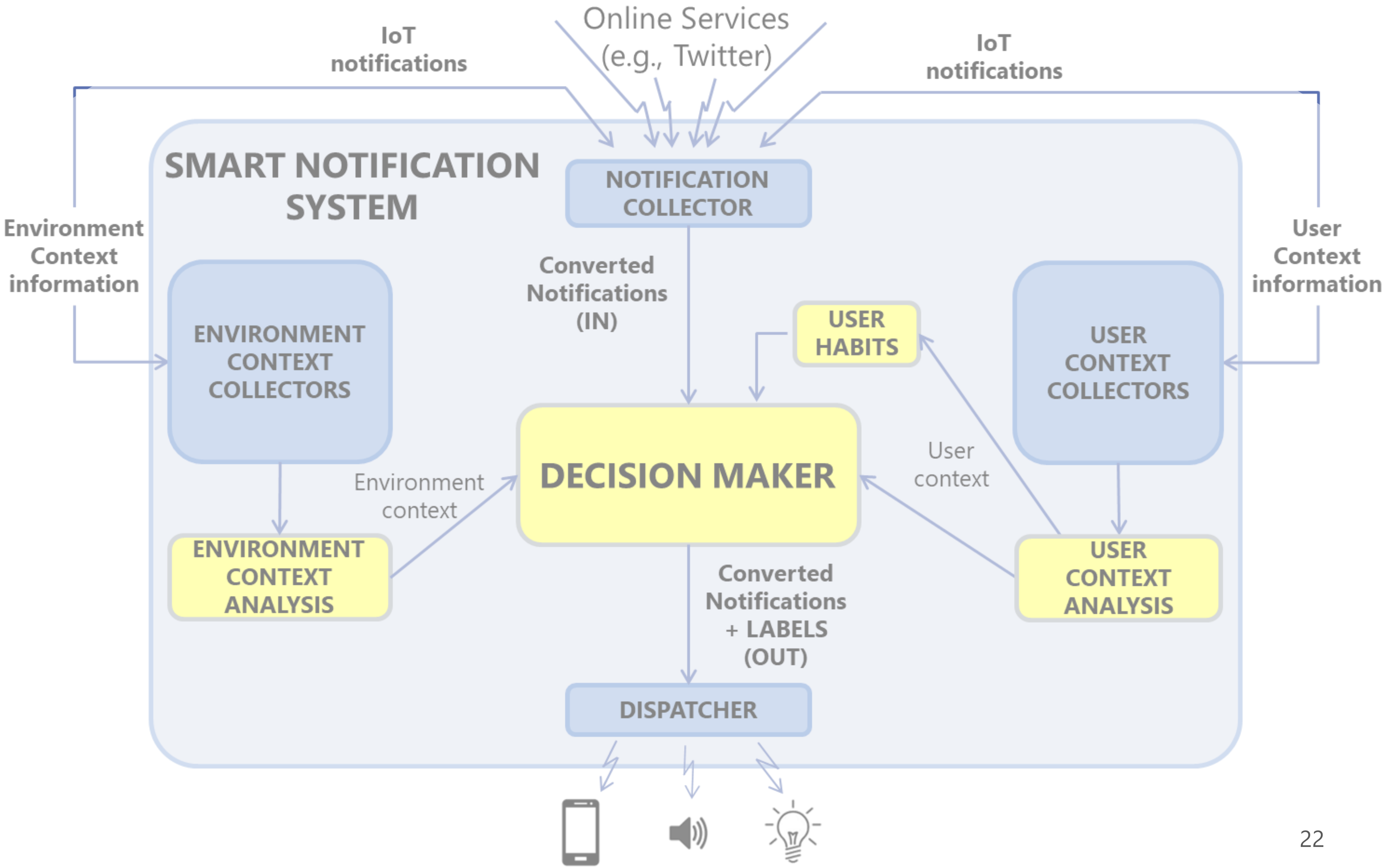
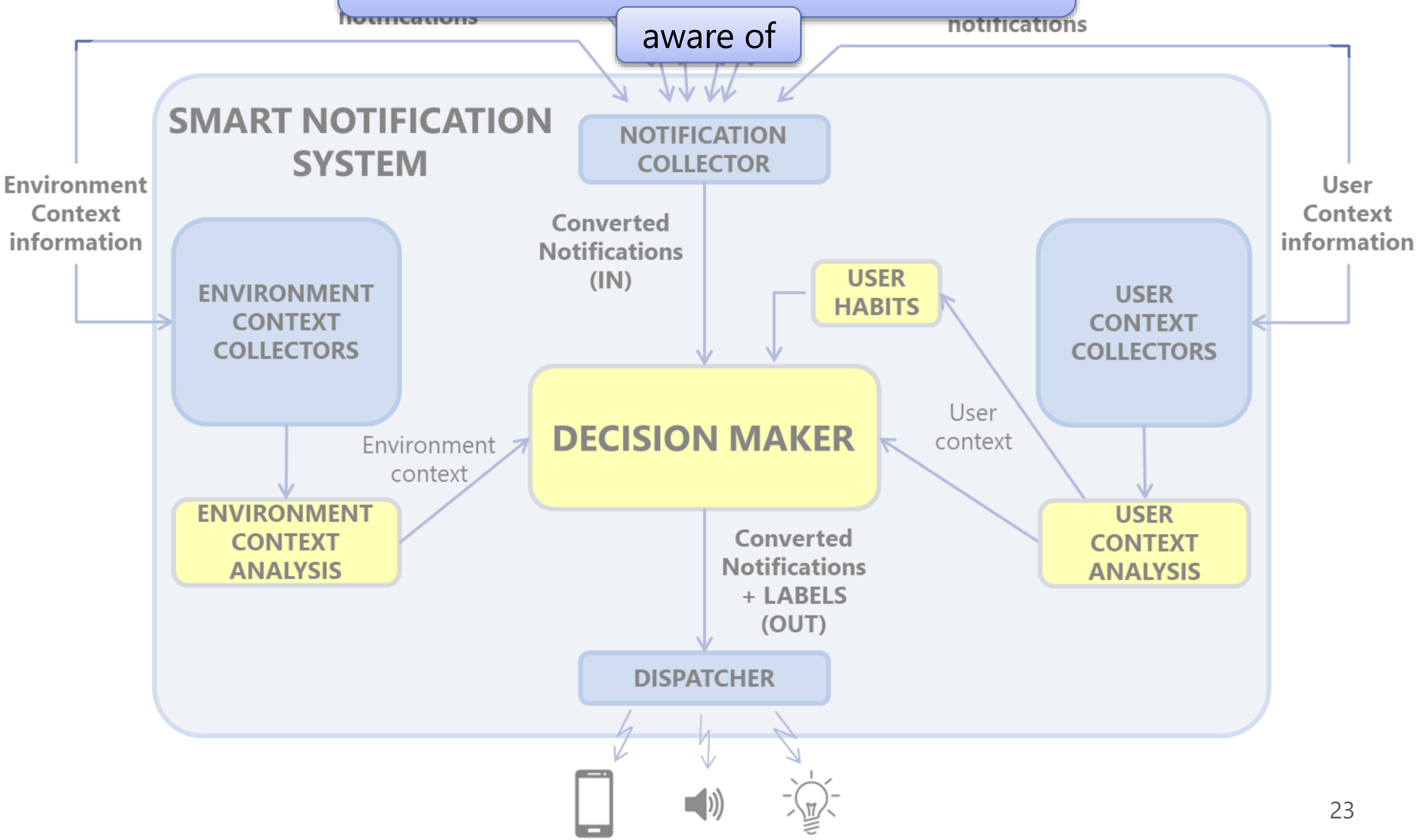


SNS: Architecture

A modular architecture

aware of



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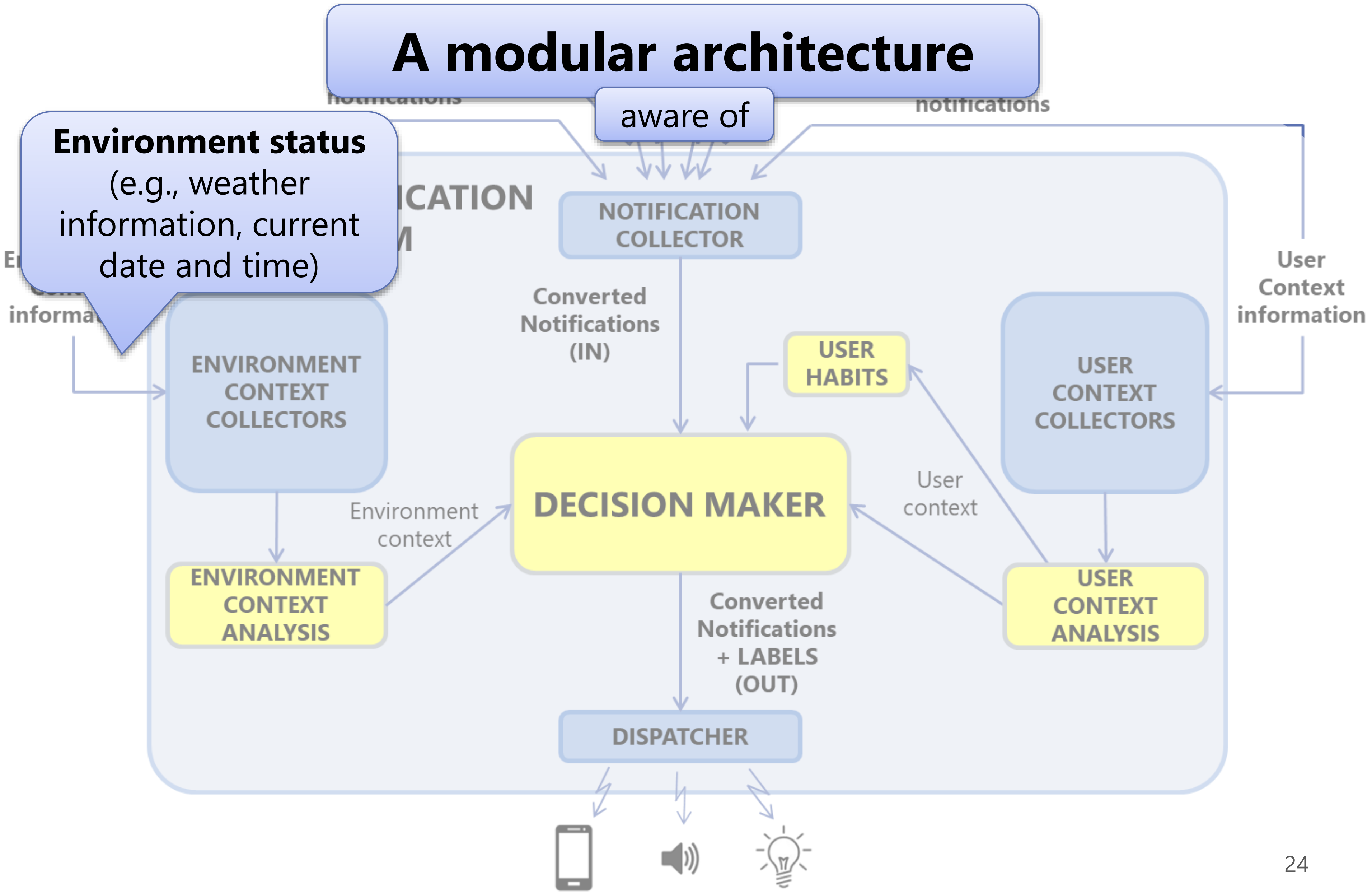


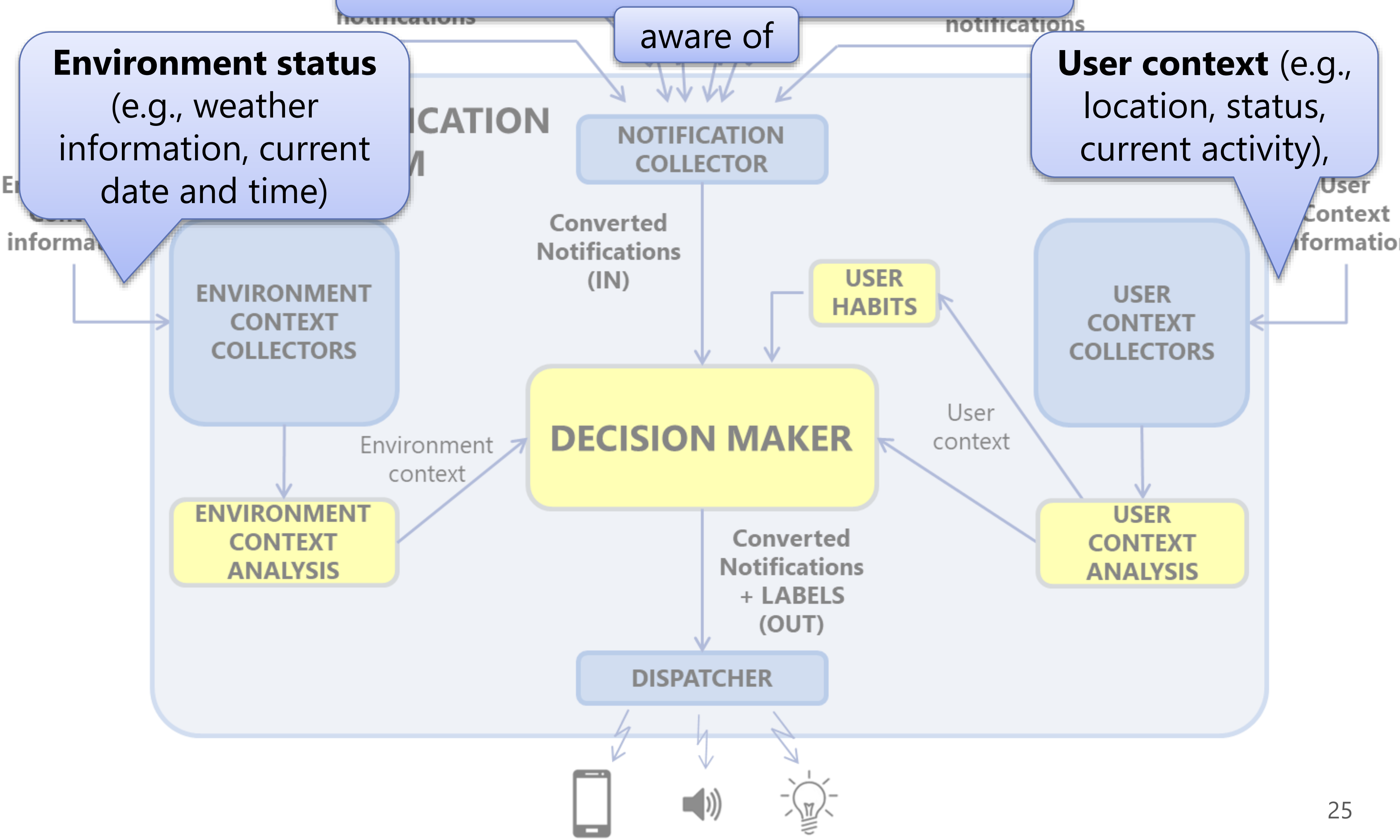
SNS: Architecture

A modular architecture

aware of

Environment status (e.g., weather information, current date and time)

User context (e.g., location, status, current activity),



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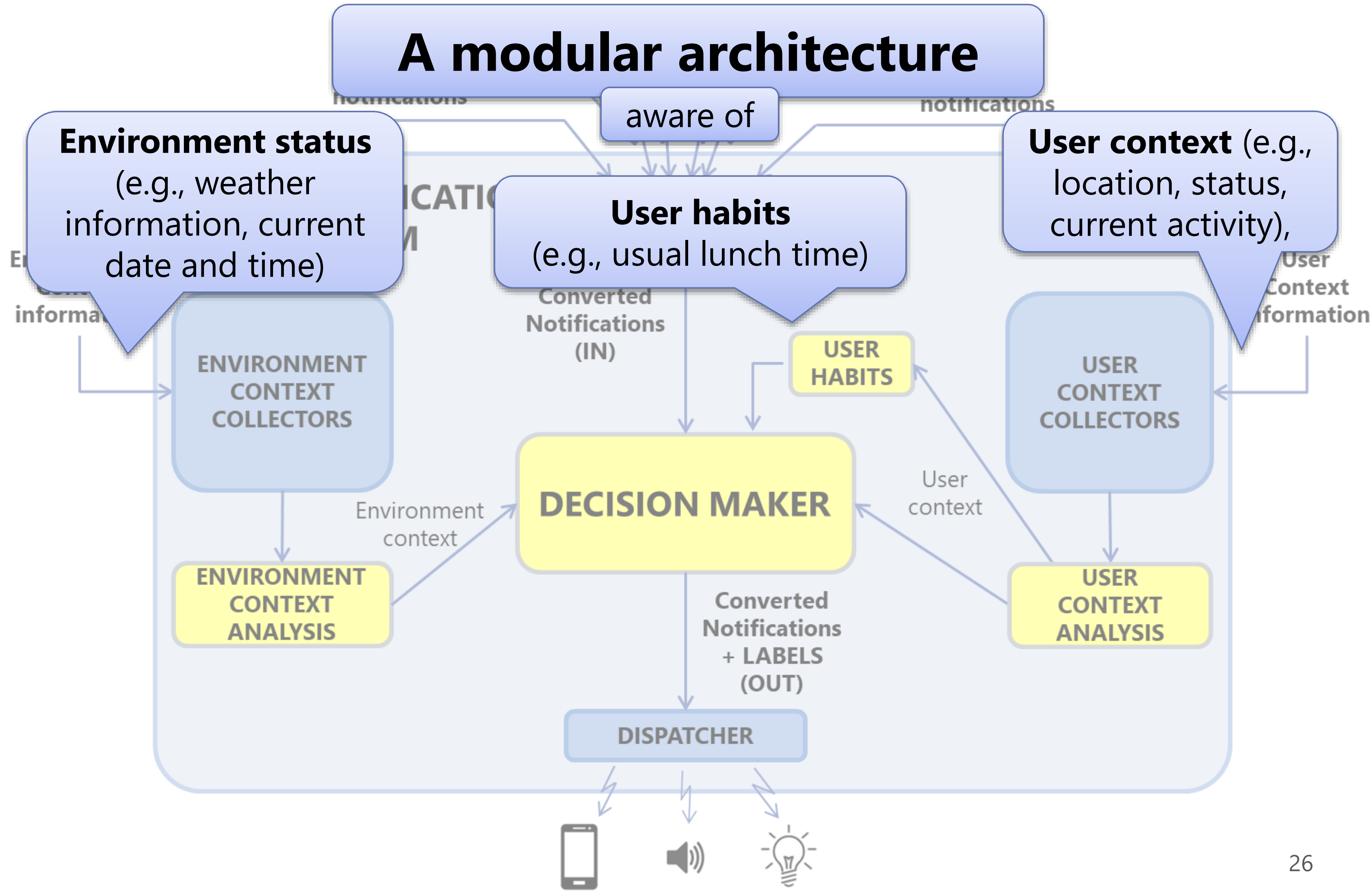

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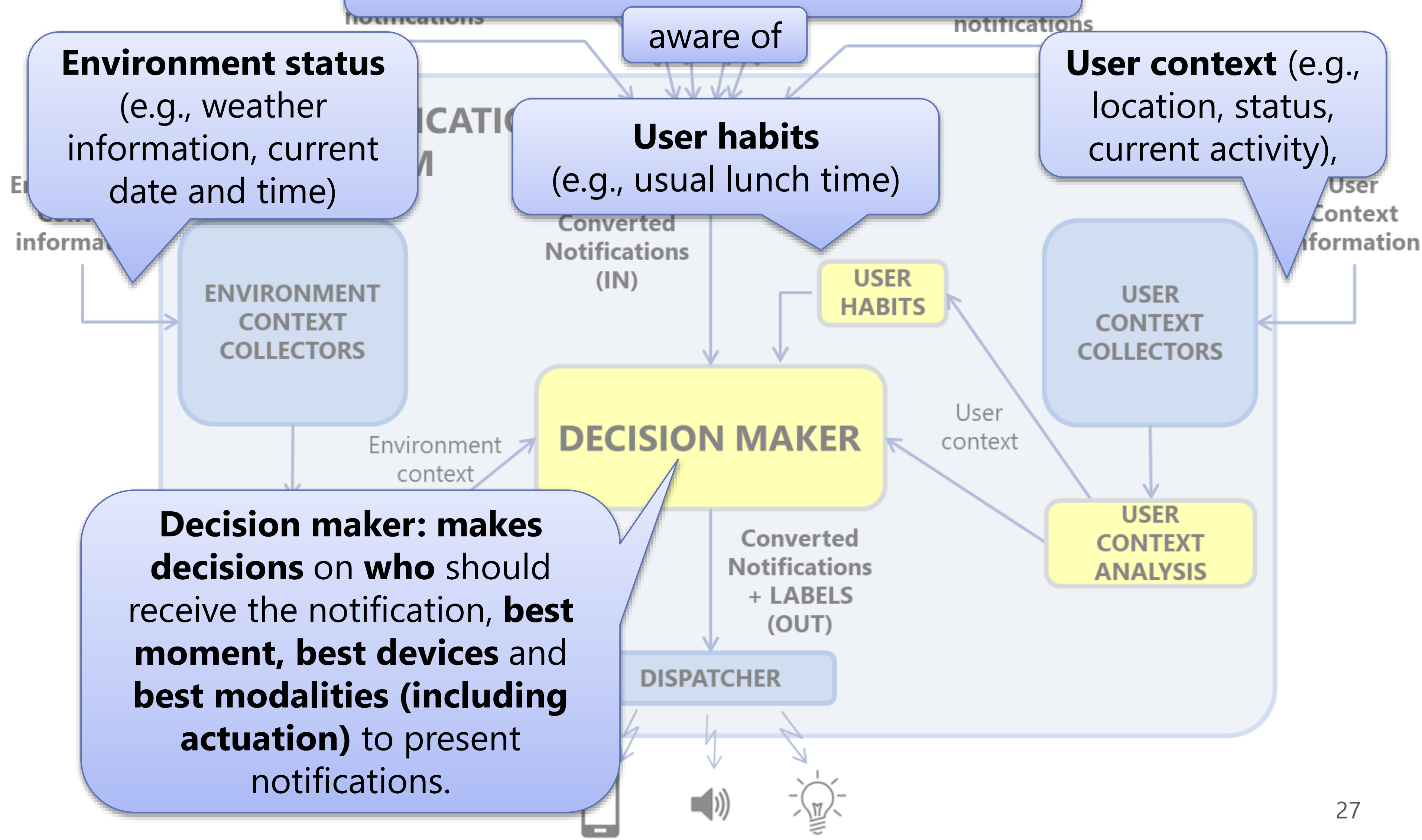


Environment status (e.g., weather information, current date and time)

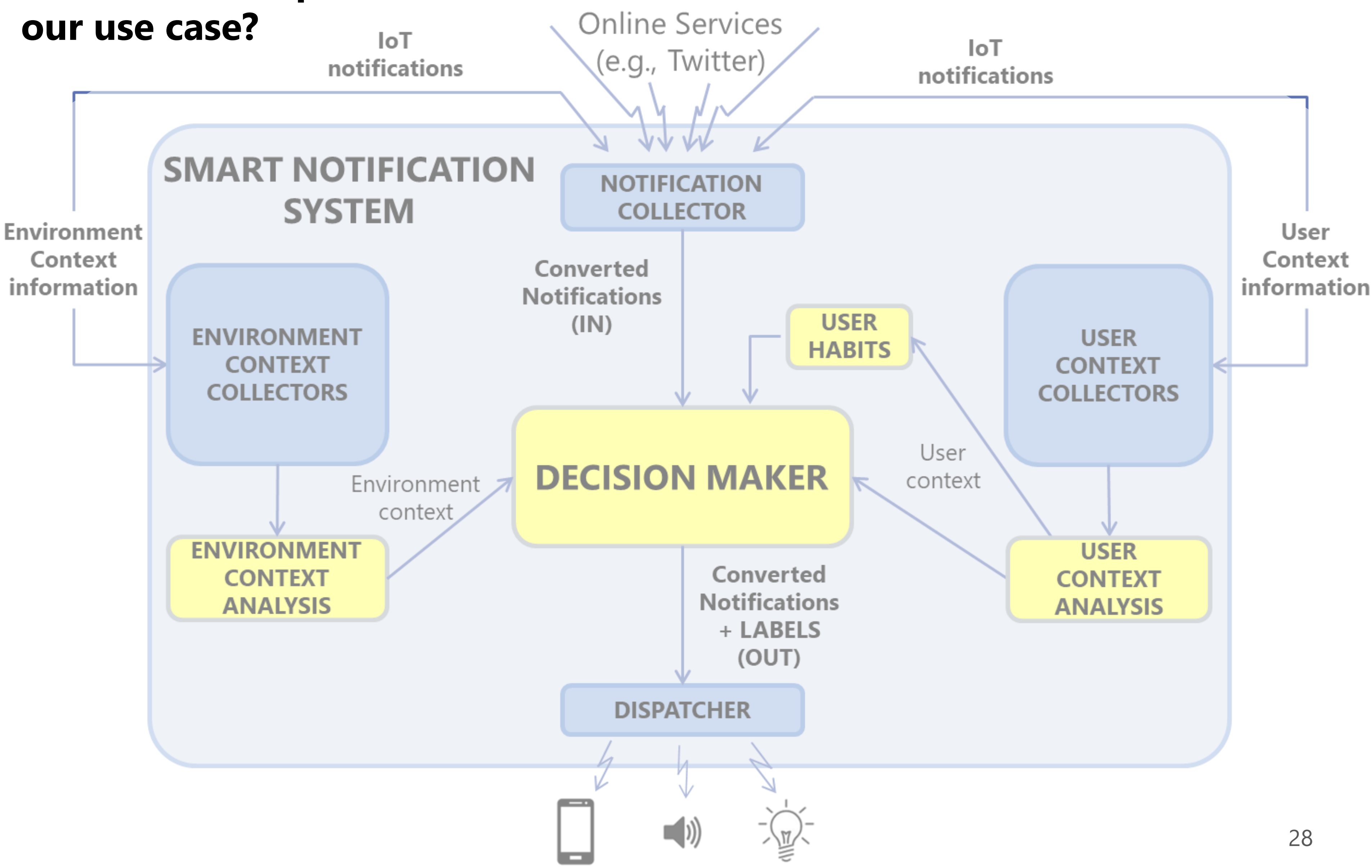
User habits (e.g., usual lunch time)

User context (e.g., location, status, current activity),

Decision maker: makes decisions on **who** should receive the notification, **best moment, best devices** and **best modalities (including actuation)** to present notifications.

SNS: Architecture

How can we map our use case?



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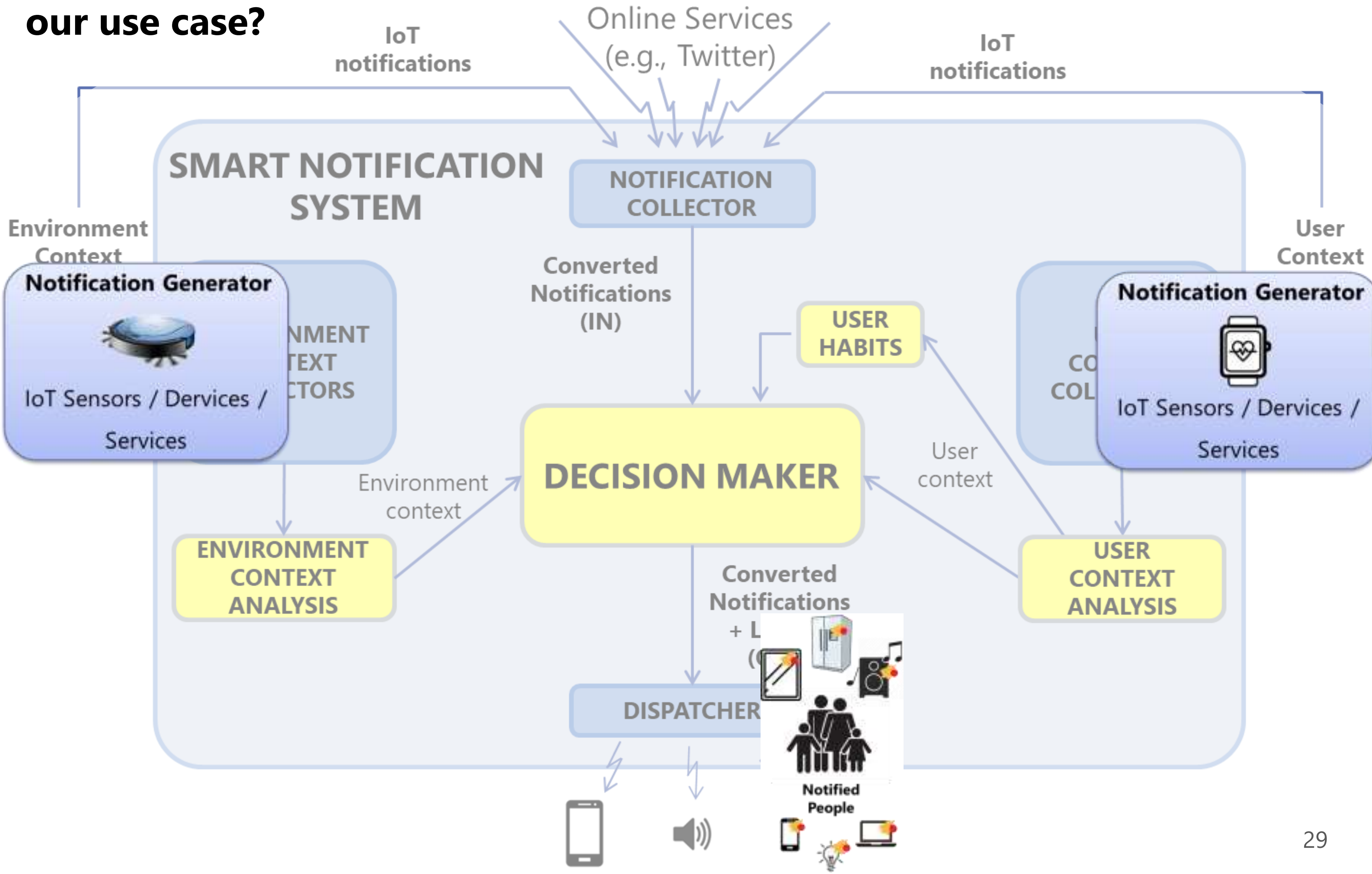
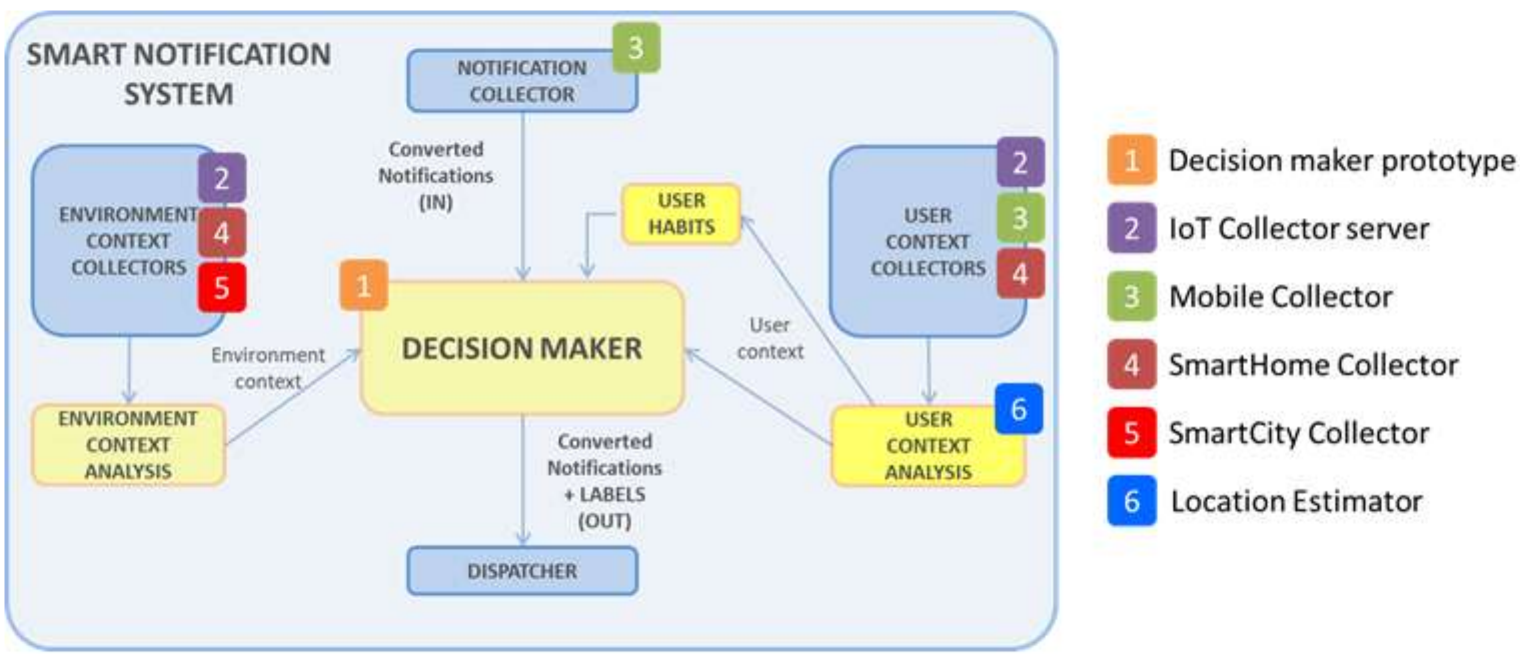


SNS: Prototypes

1. The **Decision Maker** contribution:
   a) Decision maker prototype
2. The **Collectors** group of contributions:
   a) IoT Collector server
   b) Mobile Collector
   c) SmartHome Collector
   d) SmartCity Collector
3. The **Context Analysis** group of contributions
   a) Location Estimator



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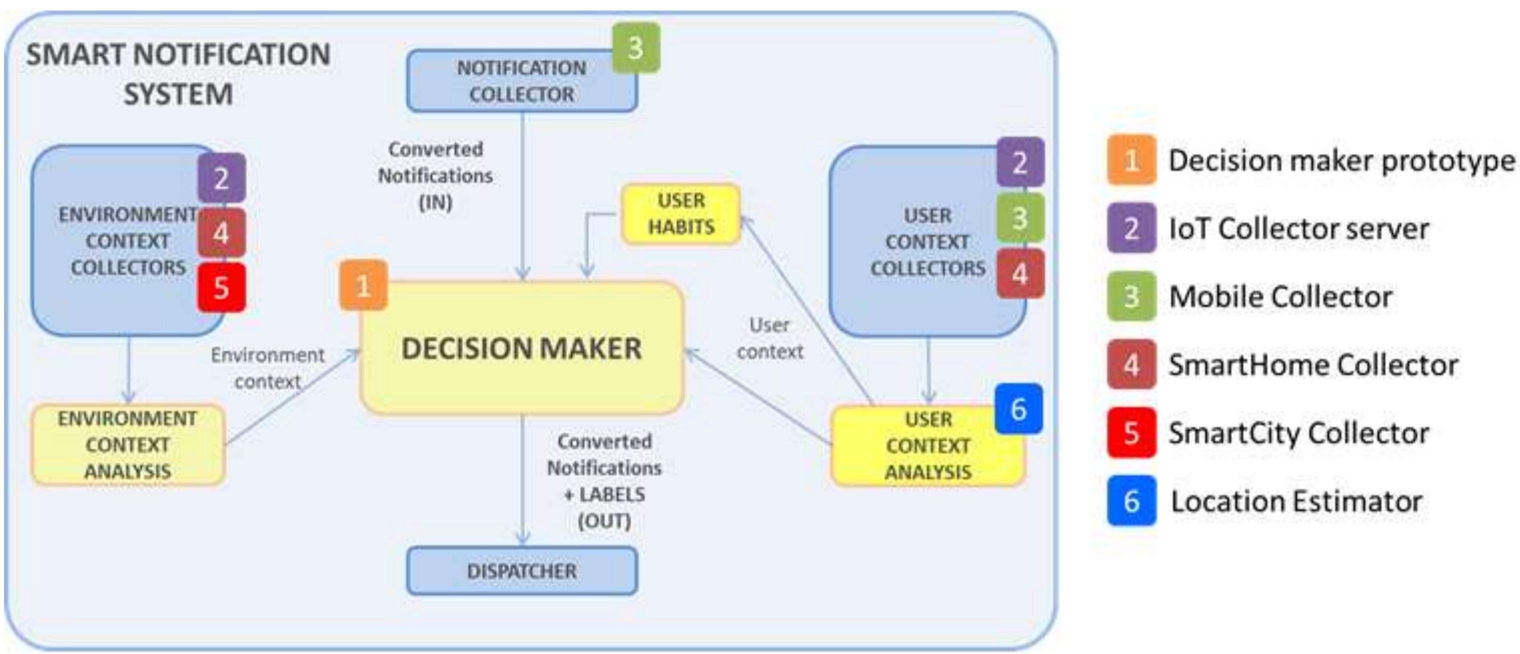

SNS: 1. Decision Maker Prototype

Objective: demonstrate that Machine Learning algorithms **can be adopted** to the IoT notifications domain
Contribution: Preliminary version of the **Decision maker module**

Context Information to be used by the ML algorithm:

User context	Current activity
	Current location
Environment context	Current timestamp
Available IoT devices information	Owner
	Current status (e.g., on, off, standby)

Table 2.7 Simplified version of Context information: for the prototype

Notification information to be used by the ML algorithm:

Information about incoming notification	Sender
	Receiver
	Type of notification
	Timestamp of receipt
Assigned labels to outgoing notifications	Target devices

Table 2.8 Simplified version of Notifications information: for the prototype

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Table 2.7 Simplified version of Context information: for the prototype

Used dataset

Reality Mining Dataset

➕ **Synthetic information**

Notification information to be used by the ML algorithm:

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Table 2.8 Simplified version of Notifications information: for the prototype

SNS: 1. Decision Maker Prototype

Objective: demonstrate that Machine Learning algorithms **can be adopted** to the IoT notifications domain

Contribution: Preliminary version of the **Decision maker module**

Tests:

- **3** different **machine learning algorithms** adopted over an existing dataset (MIT): **Support Vector Machine, Gaussian Naïve Bayes** and **Decision Trees**.

ML Algorithm	Percentage of correct predictions with unrelated data			Percentage of correct predictions with related data		
	Accuracy %	Precision %	Recall %	Accuracy %	Precision %	Recall %
Support Vector Machine	81.60	**99.89**	82.40	**96.10**	84.32	**96.90**
Gaussian Naive Bayes	51.30	99.80	51.30	83.40	**95.25**	83.40
Decision Trees	**99.90**	97.06	**99.90**	93.90	92.76	93.90

Table 2.10 Percentage of correct predictions obtained with used algorithms

Used dataset

Reality Mining Dataset

+ Synthetic information

Used tools

learn

SNS: 1. Decision Maker Prototype

Objective: demonstrate that Machine Learning algorithms **can be adopted** to the IoT notificati...

Contribu...

Tests:

- **3** diff... ...set (MIT)... ...**rees**.

Main outcome

- The **three algorithms behave as expected**:
  - **DT works better** than the others due to the **programmatic** approach used to **generate synthetic information**
  - **Almost all the algorithms** obtain an **high** level of **accuracy, precision and recall**
- ML is **promising technique** to enhance the effect of IoT notifications on users experience

dataset

Reality Mining Dataset

...ynthetic ...ormation

... tools

...Baye...						
Decision Trees	**99.90**	97.06	**99.90**	93.90	92.76	93.90

Table 2.10 Percentage of correct predictions obtained with used algorithms

SNS: Prototypes

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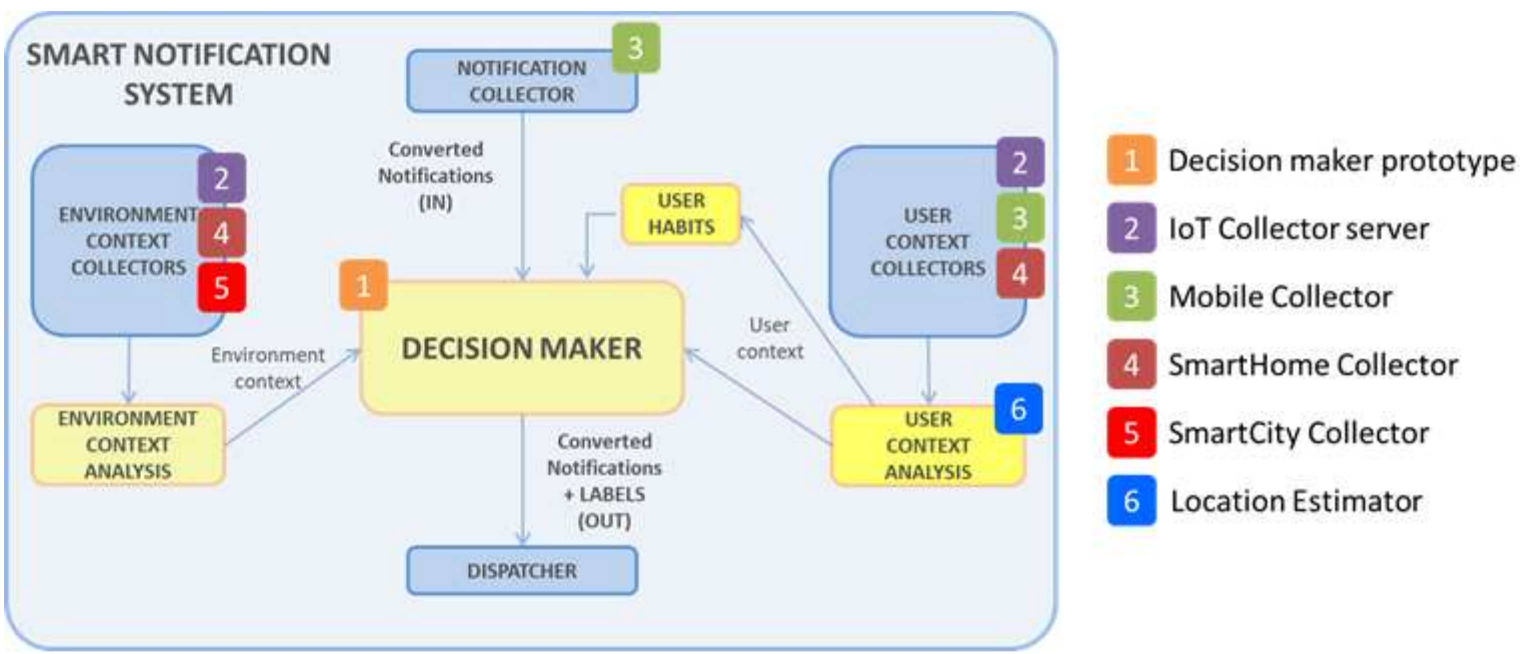
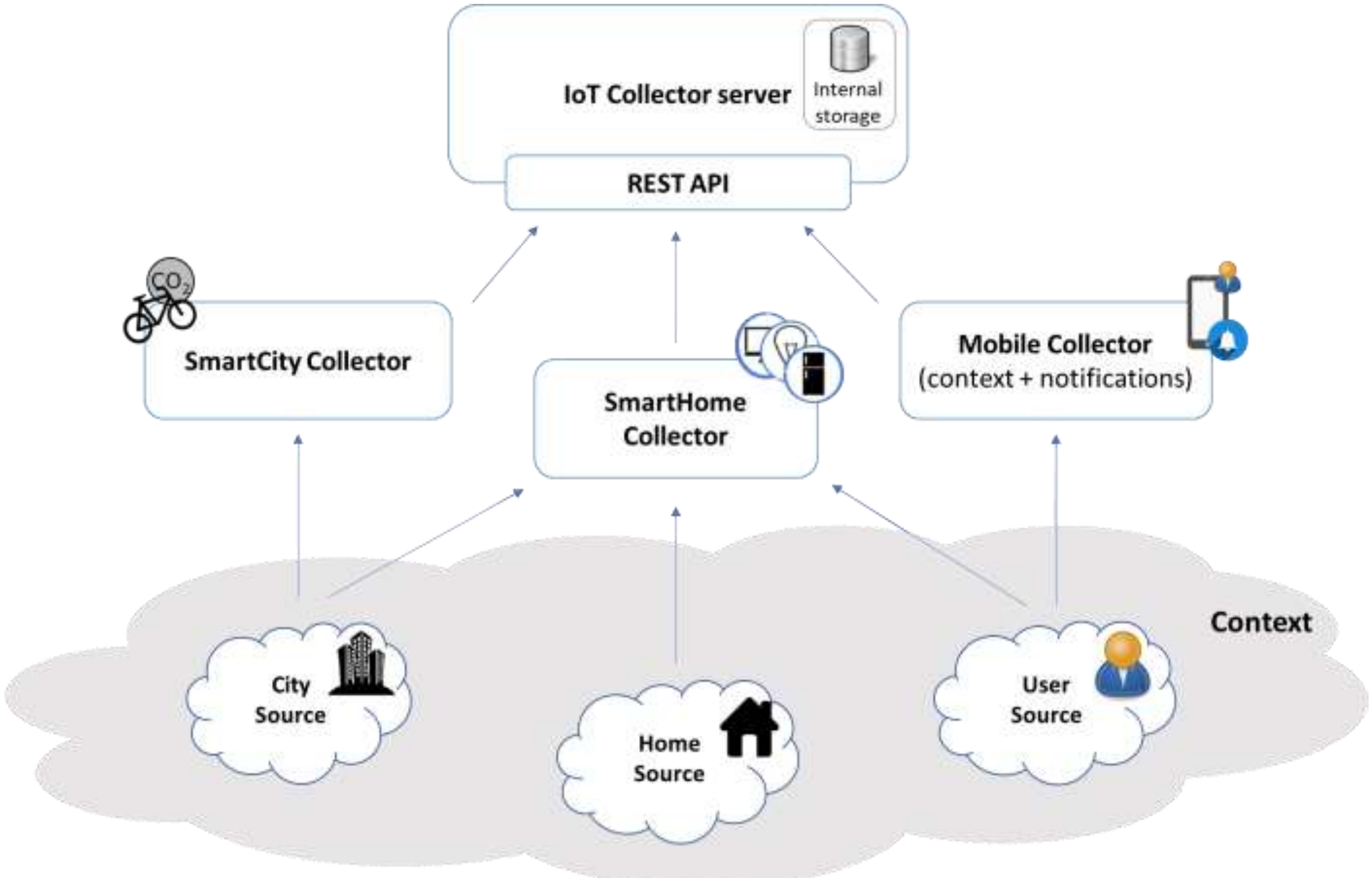


SNS: 2. Collectors

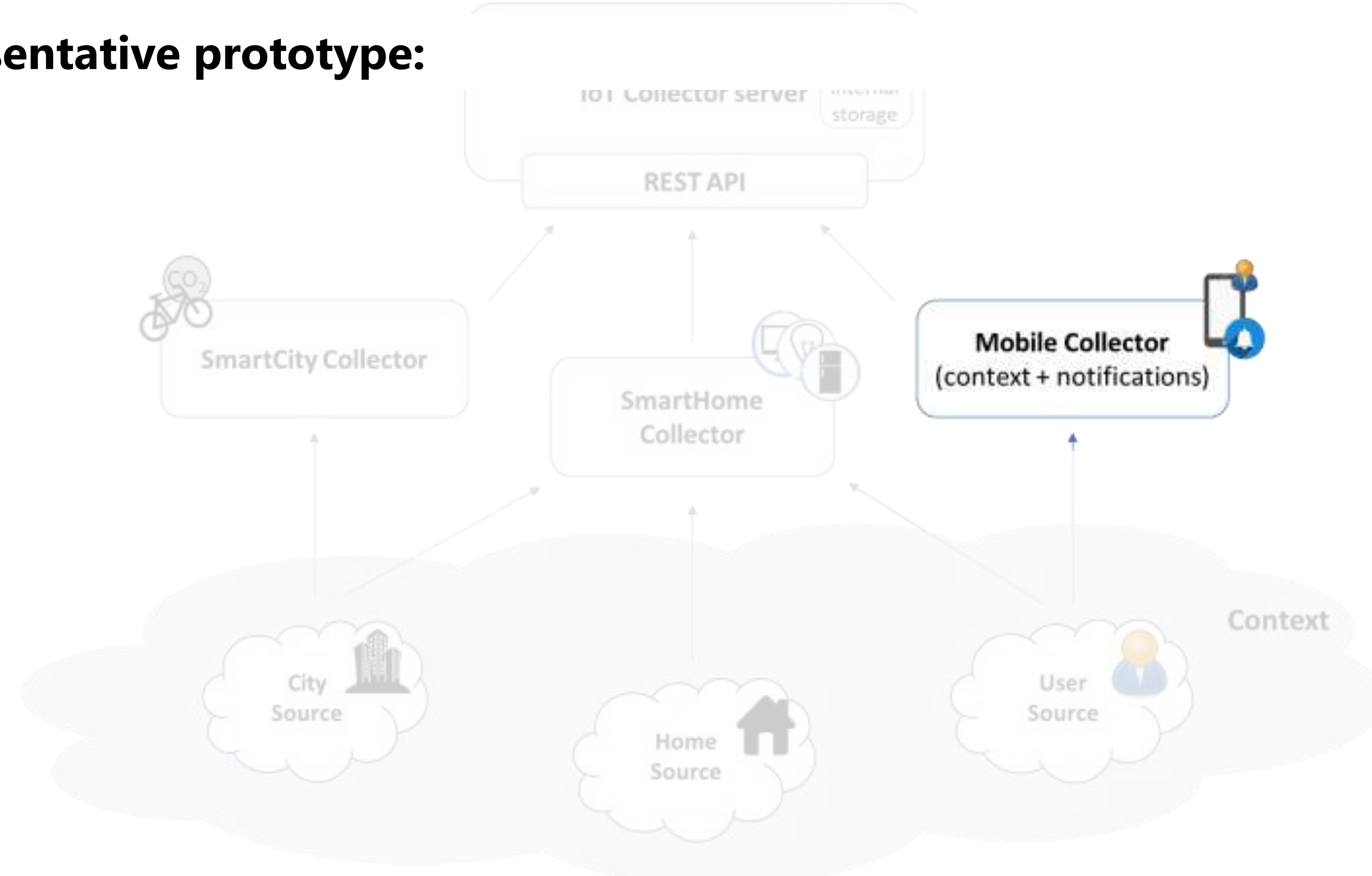
Aims:
1. collect real data
2. validate the Machine Learning approach used in the Decision Maker Prototype



SNS: 2.b Mobile Collector

Aims:
1. collect real data
2. validate the Machine Learning approach used in the Decision Maker Prototype

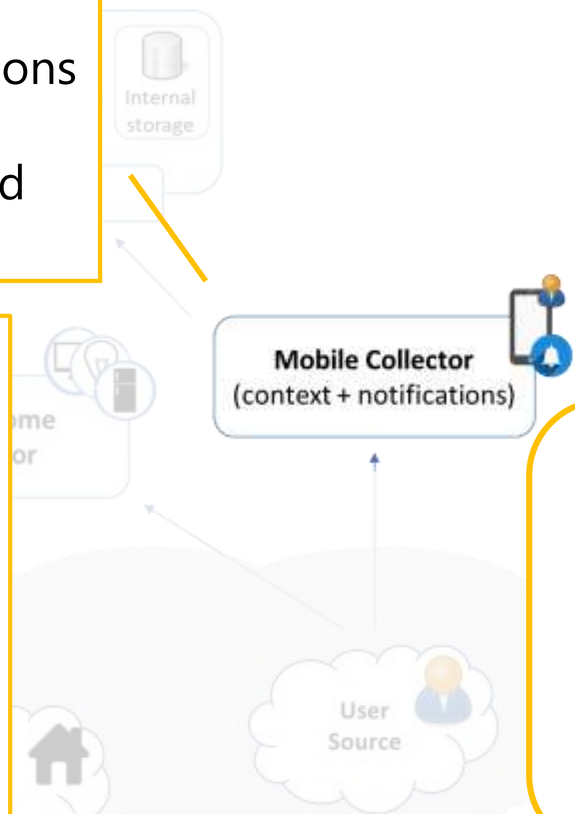
Representative prototype:



SNS: 2.b Mobile Collector

Objective 1: collect real user data

- Collect user context information (e.g., location and activity);
- Collect all the mobile and IoT notifications received on user smartphone;
- Collect the user reaction to the received notifications.



29 people (5 females and 24 males) used the app for **78 days**

- users receives an average of 247 notifications a day
- users are almost always in the same 3 or 4 places
- users receive most of the notifications from non-important contacts than from important ones.

Used tools

SNS: 2.b Mobile Collector

Objective 2: validate the Machine Learning approach used in the Decision Maker Prototype

Input features:

- Notification type (mobile, IoT)
- Generating service (e.g., Telegram)
- Ringtone mode
- Notification sender
- Sender-Receiver FAMILY relationship
- Sender-Receiver FRIEND relationship
- Sender-Receiver WORK relationship
- Date and time of receipt (day of week, day of month, month, time)
- User location (Lon/Lat)
- Activity (IN_VEHICLE, ON_BICYCLE, ON_FOOT, RUNNING, STILL, TILTING, UNKNOWN, WALKING)
- Battery level
- Battery status (charging or not charging).
- Connection type (Wifi, network, NoConn)
- Wifi SSID

Label: annoying or appreciated notification (14 users for 15 days)

User	% of appreciated notifications over all	Naïve Bayes			J48 (Decision Trees)		
		accuracy	precision	recall	accuracy	precision	recall
User 1	62%	75%	75%	75%	69%	69%	69%
User 2	70%	94%	94%	94%	99%	99%	99%
User 3	96%	92%	91%	92%	95%	91%	95%
User 4	63%	60%	63%	60%	68%	68%	68%
User 5	81%	92%	94%	92%	92%	91%	92%
User 6	65%	58%	56%	58%	58%	53%	58%
User 7	54%	78%	78%	78%	83%	83%	83%
User 8	72%	72%	78%	72%	70%	65%	70%
User 9	57%	67%	68%	67%	60%	59%	60%
User 10	77%	72%	75%	72%	70%	64%	70%
User 11	66%	70%	70%	70%	74%	81%	74%
User 12	61%	82%	82%	82%	91%	92%	91%
User 13	53%	78%	82%	78%	88%	88%	88%
User 14	87%	74%	76%	74%	89%	80%	89%
Mean		76%	77%	76%	79%	77%	79%
Standard deviation		11%	11%	11%	13%	13%	13%

Table 2.17 Preliminary results with real data

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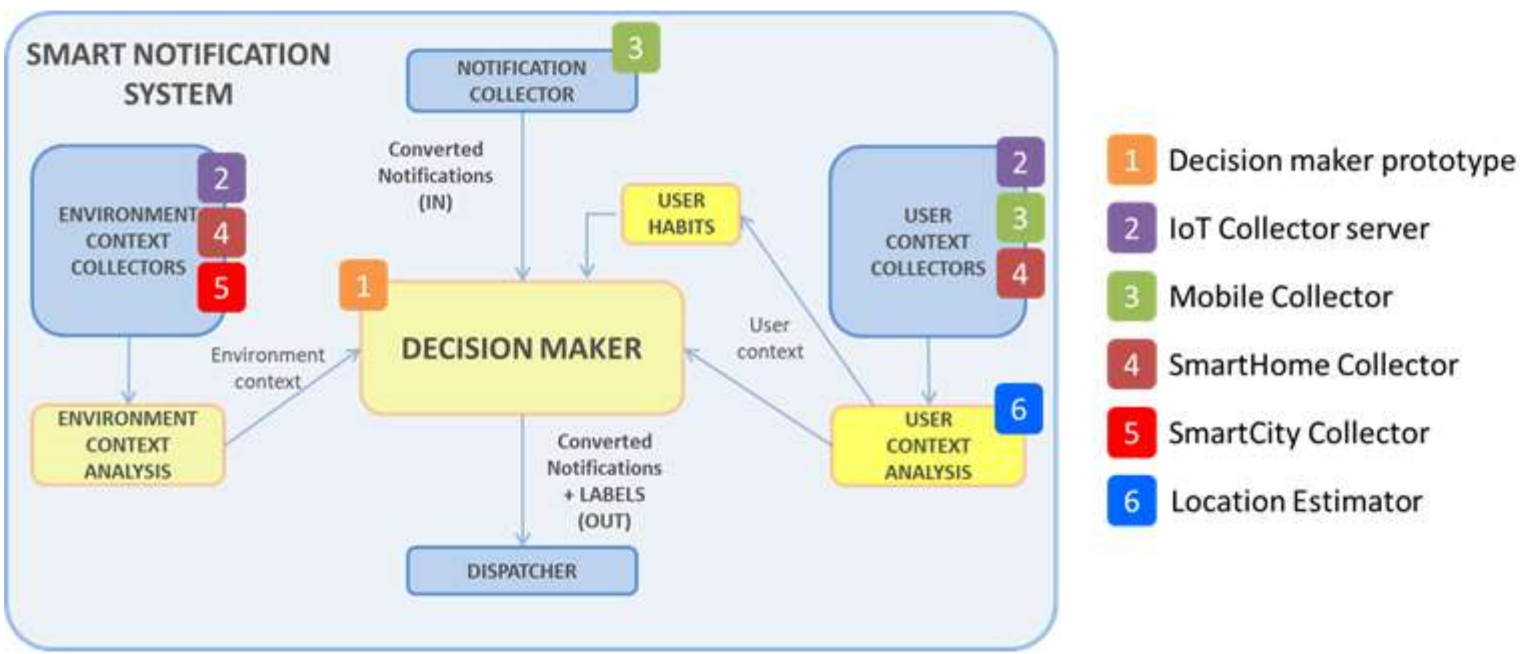
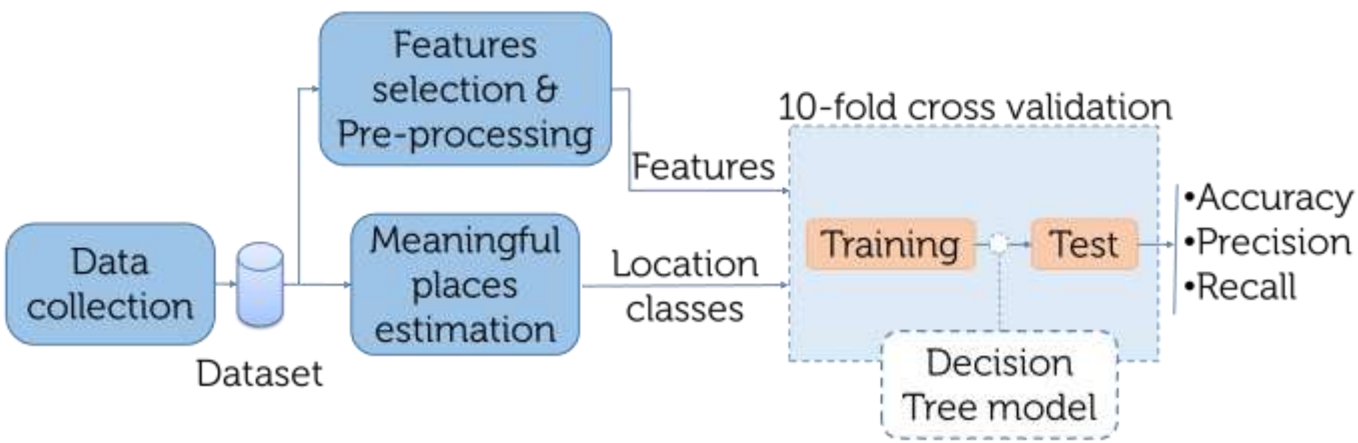


SNS: 3. Context Analysis: location estimation

Proposal: demonstrate possibility of inferring user location without energy-hungry methods (e.g., GPS)

People usually spend 85% of their time staying in a few places.
The proposed solution uses Decision Trees as Machine Learning supervised classification algorithm to establish user presence in the **two most attended meaningful places**



Model that describes the estimation process performed for each user

SNS: 3. Context Analysis: location estimation

Proposal: demonstrate possibility of inferring user location without energy-hungry methods (e.g., GPS)

Tests:

- 10-fold cross validation through the Weka workbench
- **user presence in a meaningful place** was **estimated** every time a new notification is received.
- **Input features**: combination of Feature Classes (A-AB-ABC-ABCD-ABCDE-BC-…)

Category	Feature	Feature Class
Time information	Time	A
	Month	
	Day	
	Day of the week	
Notification information	Type	B
	Generating service	
	Sender-receiver relationship	
Device state	Battery level	C
	Charging state	
	Ringtone mode	D
User information	Current activity	E
	Absolute location	-

TABLE 1: Collected data

Results:

- Most important features (that mainly influence decision) are related to **time**
- **"Current activity" (E)** (i.e., the only feature that consumes extra energy), is **not necessary**
- **Accuracy>75%** in almost all tests

XDN Framework

XDN: Motivation

Main Problem: Overwhelming notifications

Second approach

- At the **design level**: notifications are designed with the aim of reducing user disruption

XDN: Motivation

Main Problem: Overwhelming notifications

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Developers:

- **define their strategies** to let their software, then, influence users' behaviors with respect to notifications
- **exploiting** the **advantages** of the **cross-device** approach

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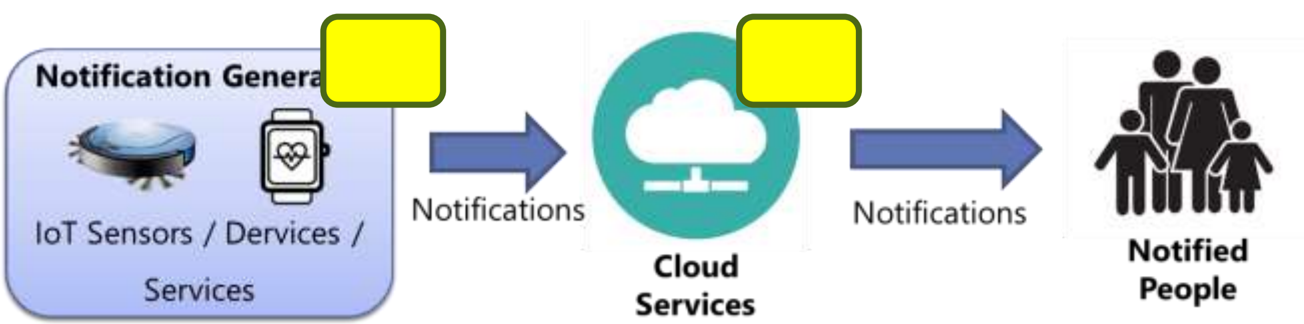

XDN: Our Proposal

Main Problem: Overwhelming notifications

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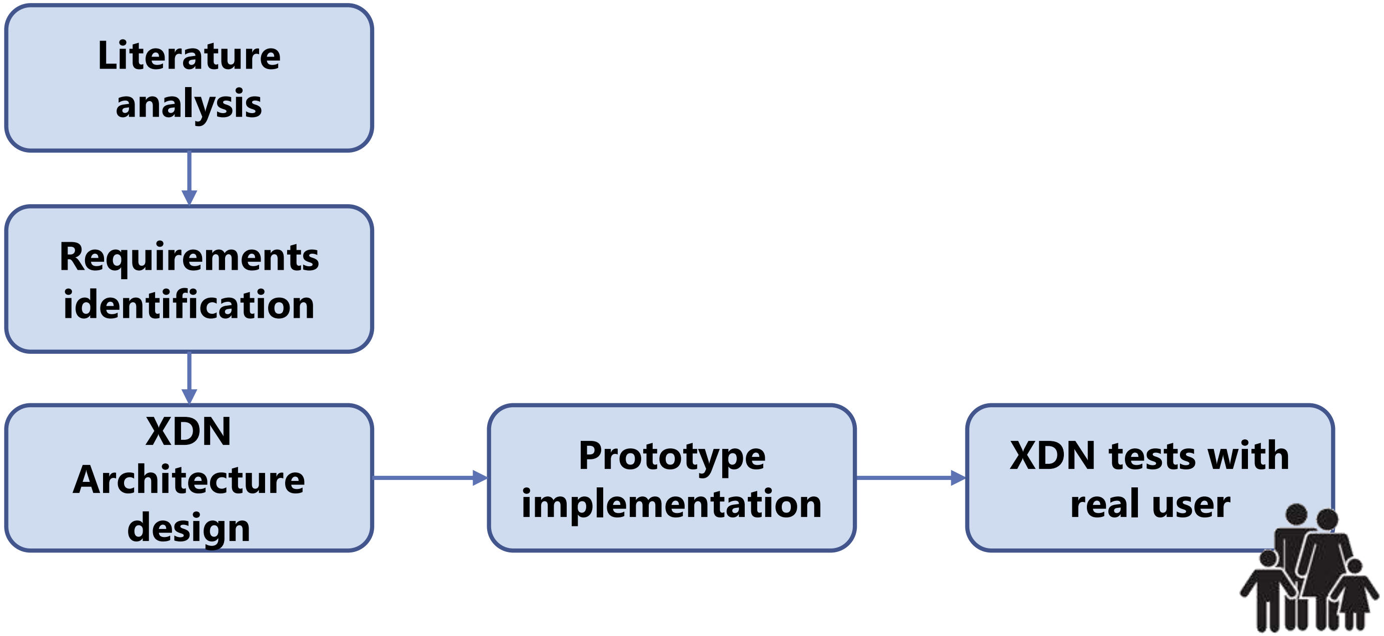
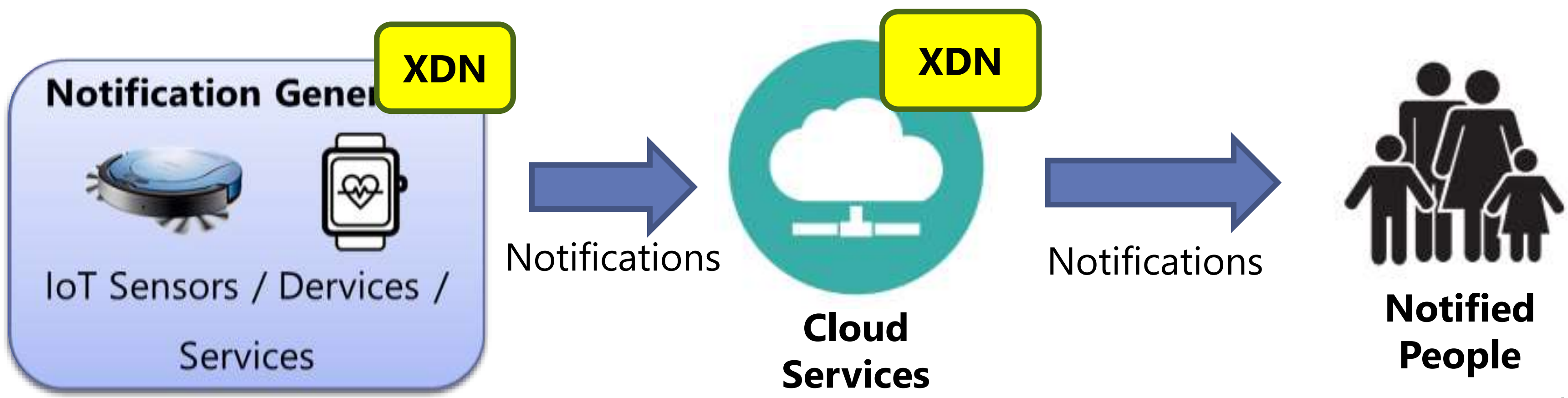


XDN: Our Proposal

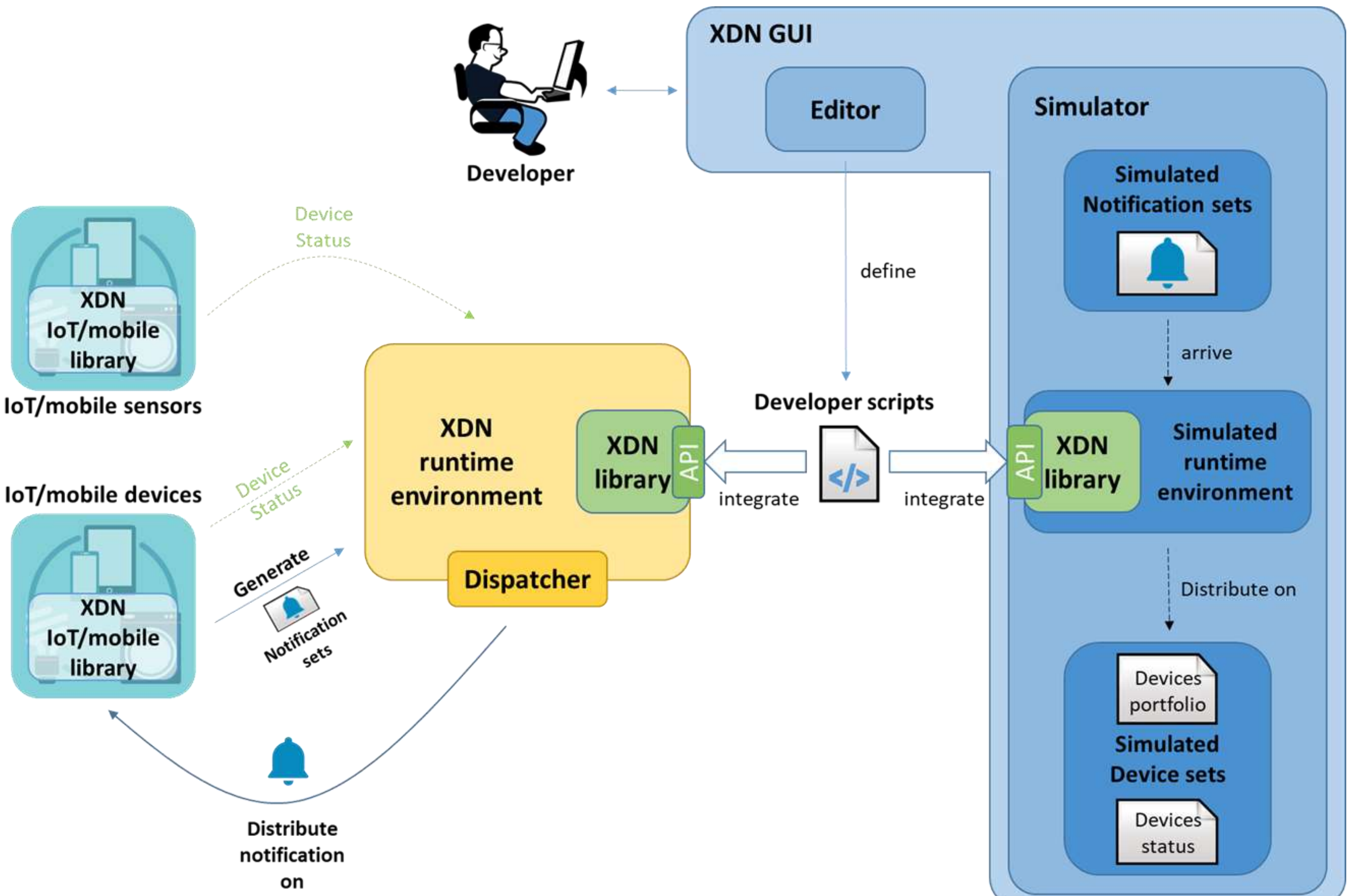
XDN (Cross Device Notifications), a framework to assist **developers** in:

a) **personalizing notifications** to differentiate important and unimportant ones

b) **designing, implementing, and testing cross-device notifications strategies** to inform users without causing too much disruption and involving both mobile and IoT devices.



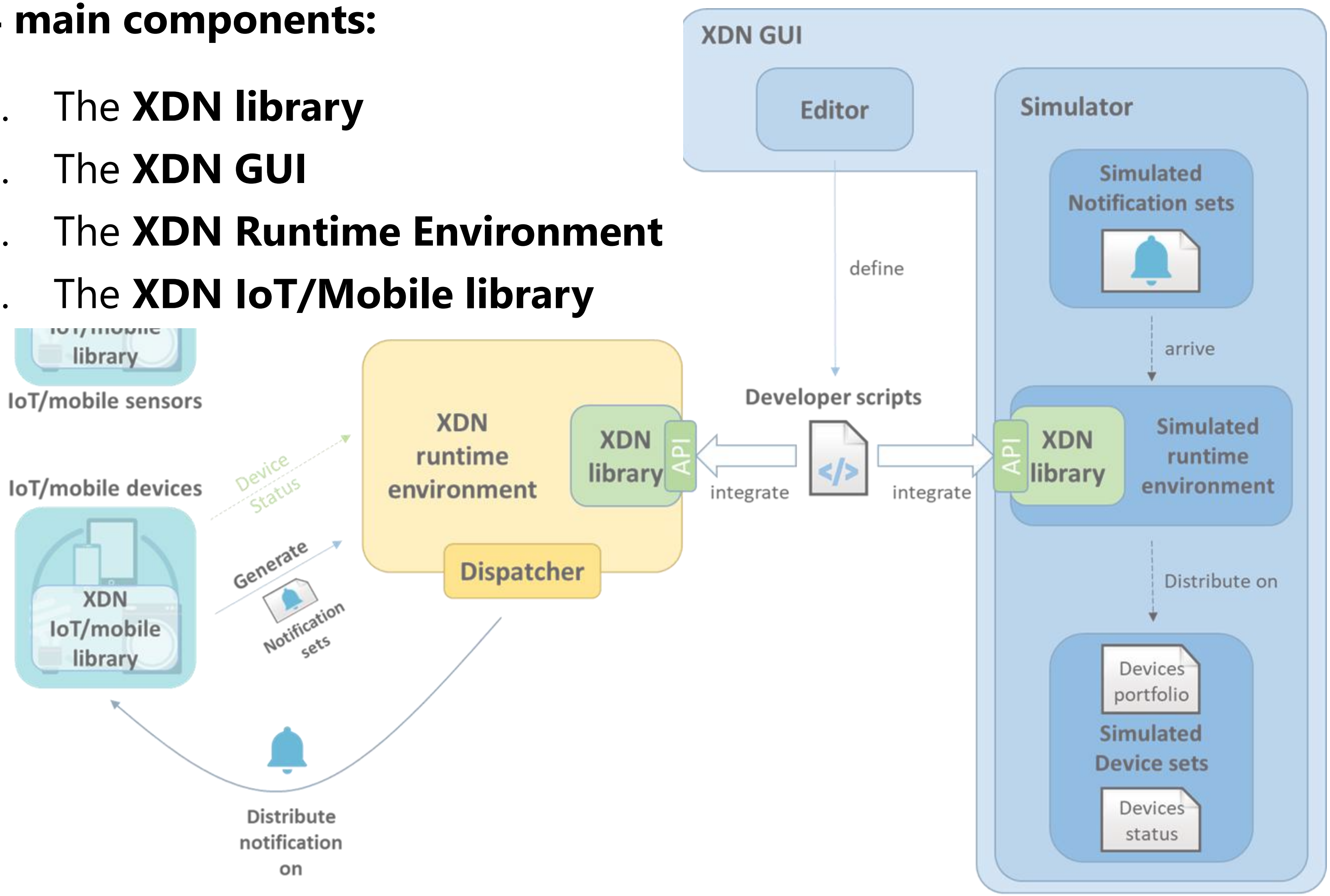
XDN: Architecture



XDN: Architecture

4 main components:

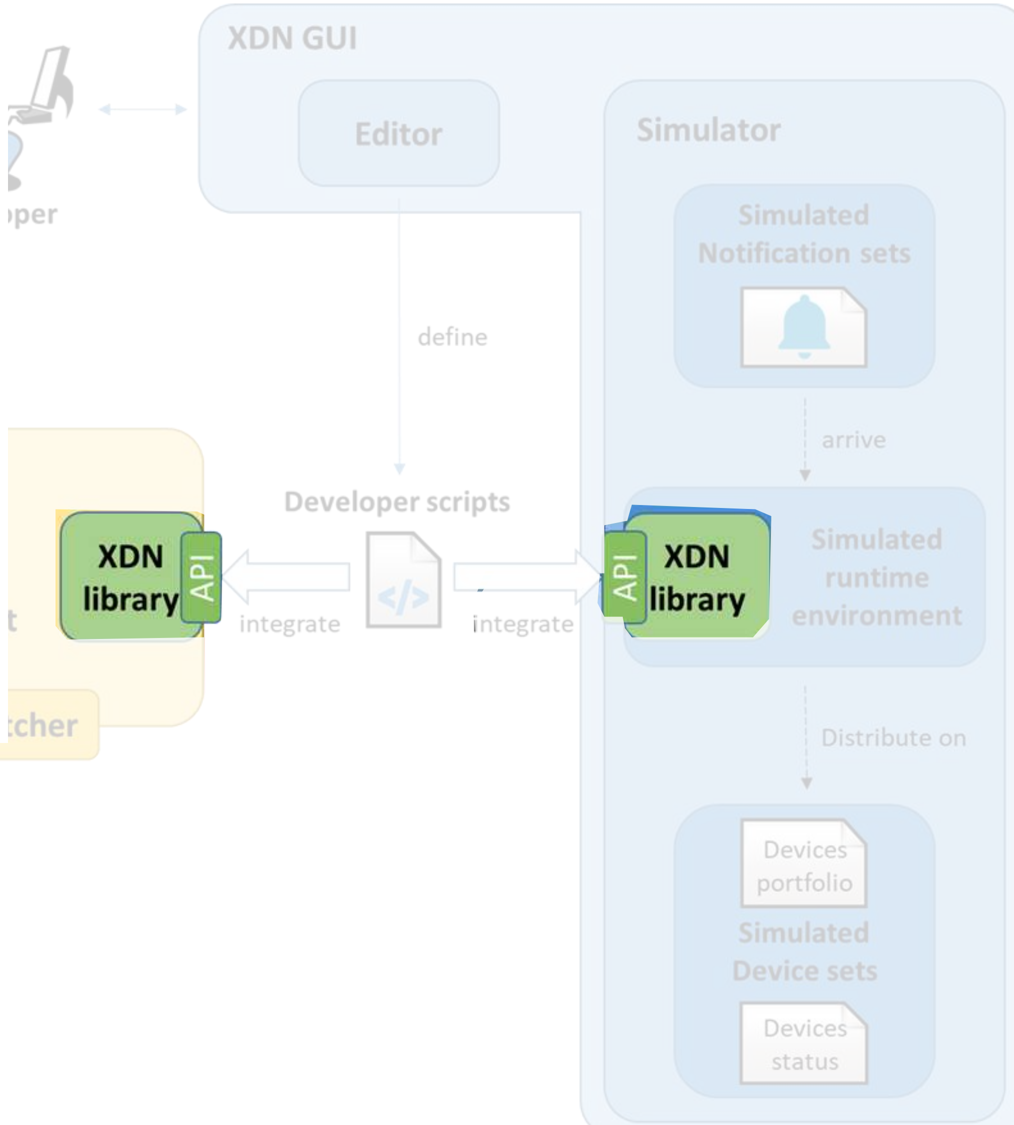
1. The **XDN library**
2. The **XDN GUI**
3. The **XDN Runtime Environment**
4. The **XDN IoT/Mobile library**



XDN: Architecture

4 main components:

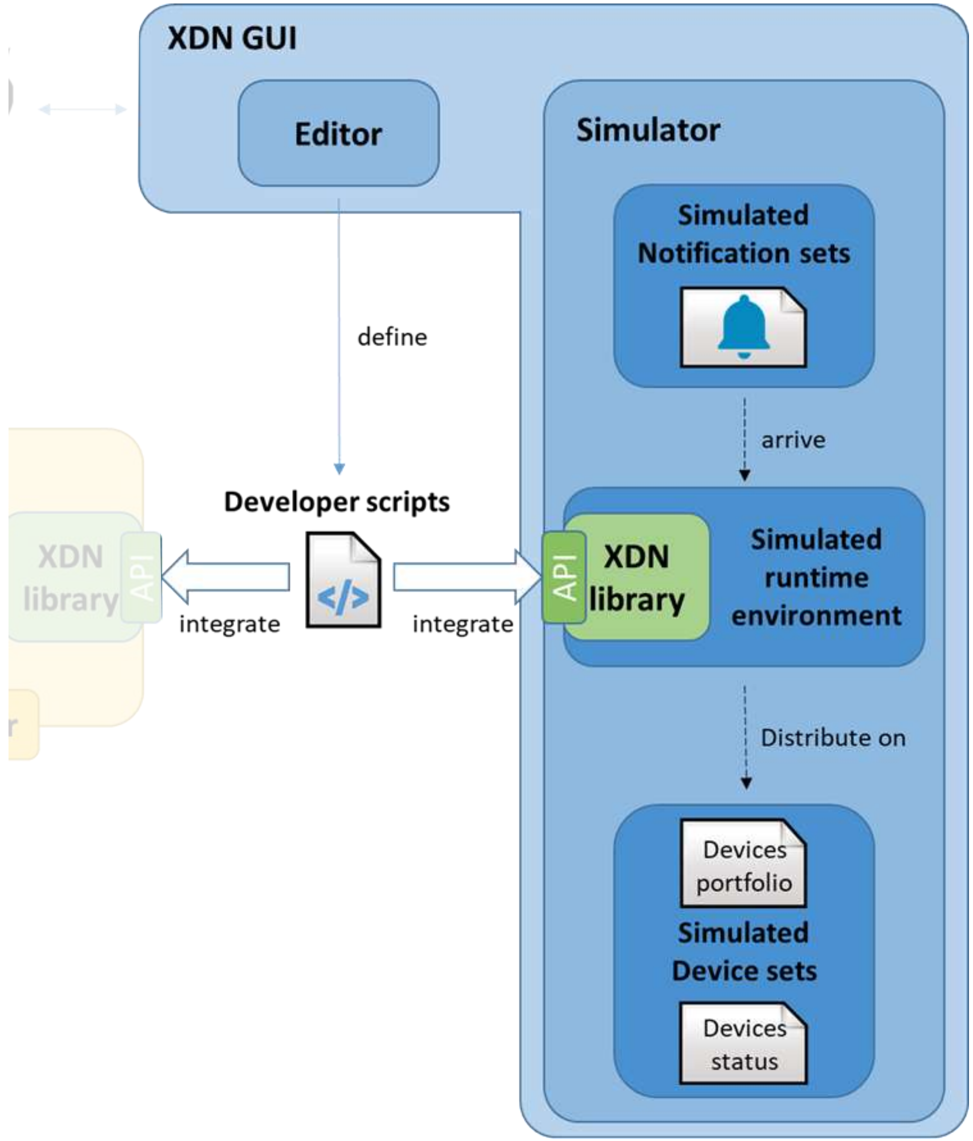
1. The **XDN library** allows (through APIs) to:
   - a) handle incoming notifications
   - b) select devices to be involved
   - c) perform actions on selected devices



XDN: Architecture

4 main components:

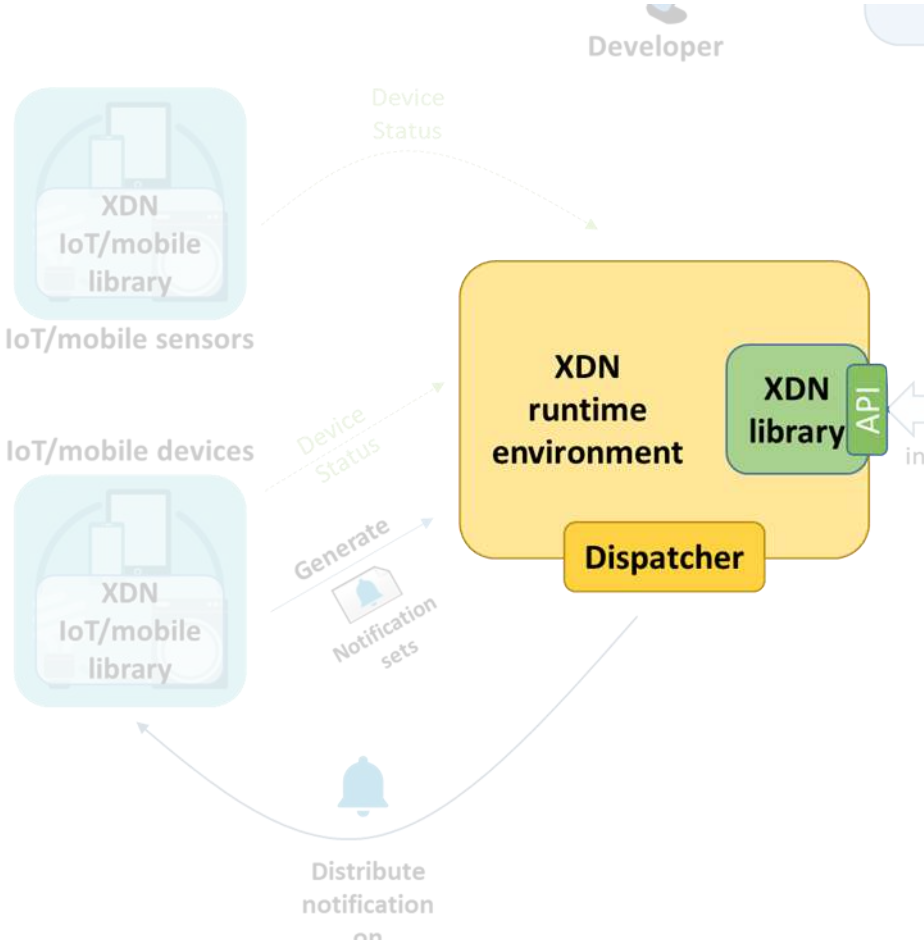
2. The **XDN GUI** allows developers to **explore and evaluate different design alternatives** by providing:
   a) an **IDE** to implement and test developed notification strategies
   b) a **simulator** to simulate the behavior of the devices



XDN: Architecture

4 main components:

3. The **XDN Runtime Environment** is run on a server to:



- accept device registration requests;
- accept update requests
- accept new notifications
- customize and dispatch the notifications

XDN: Architecture

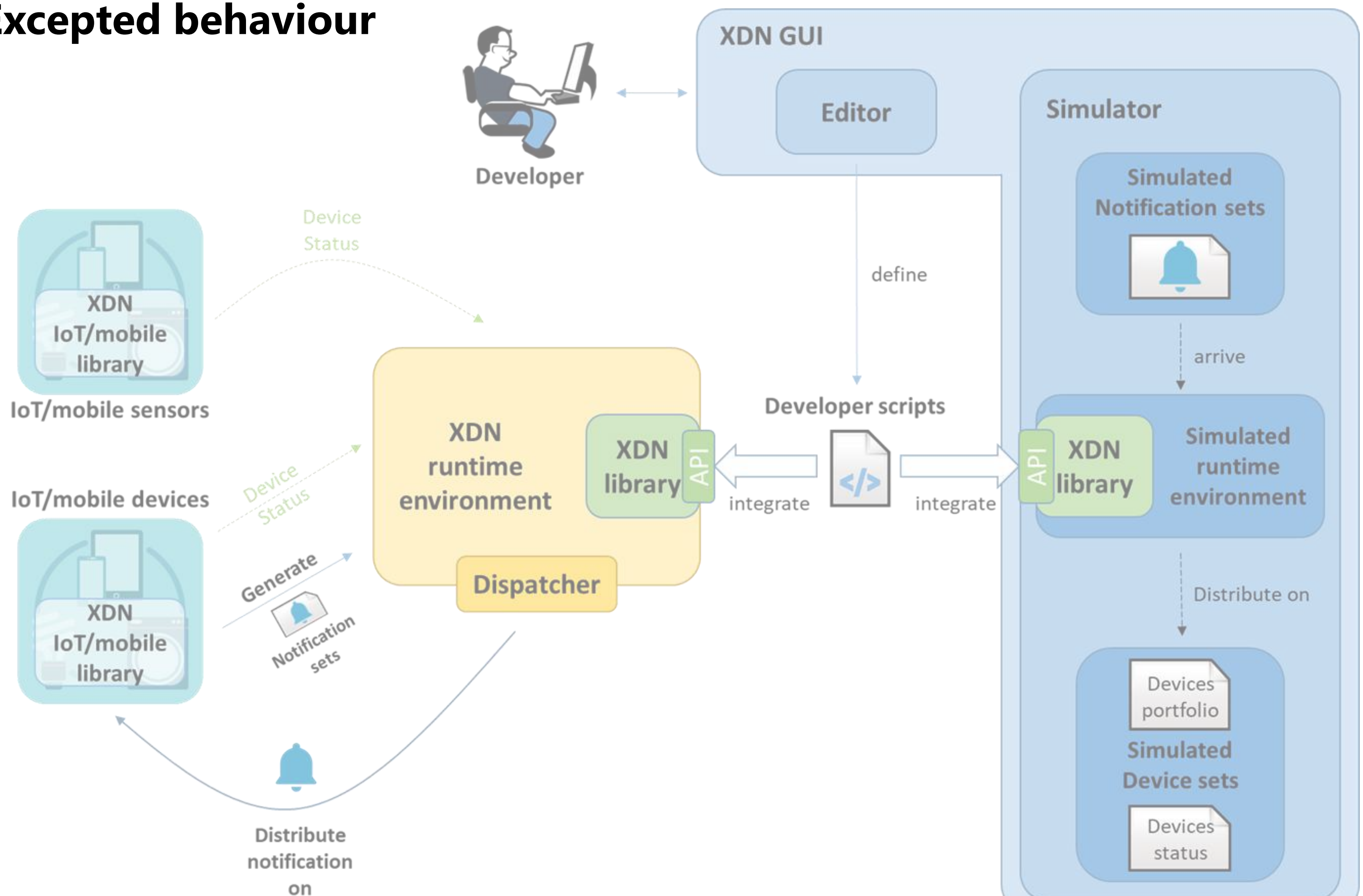
4 main components:

4. The **XDN IoT/Mobile library** to be integrated in the IoT/mobile applications to:

- generate notifications compatible with XDN
- send the generated notifications to the XDN runtime environment;
- receive commands from the XDN runtime environment (in JSON)
- execute the received commands.

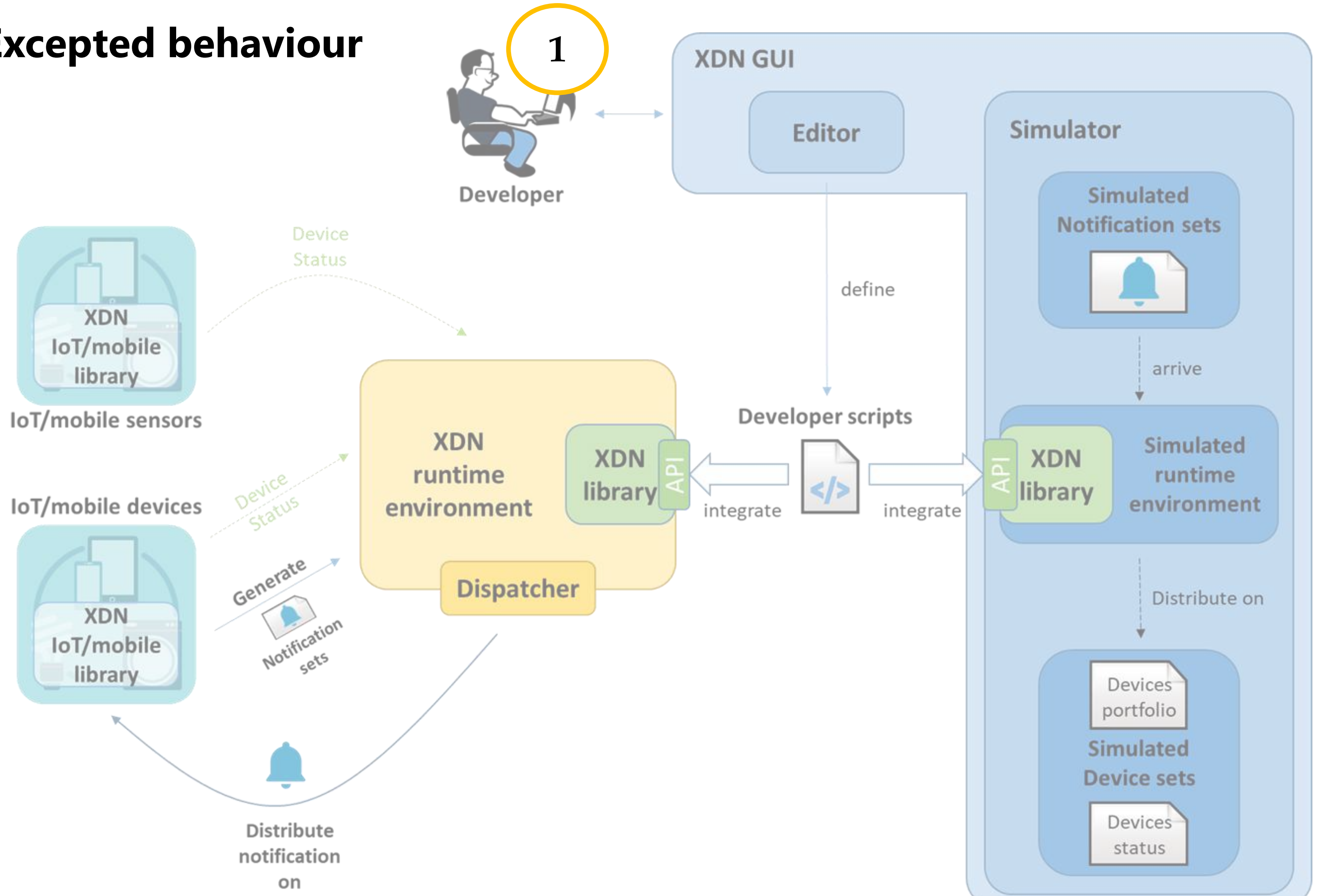
XDN: Architecture

Excepted behaviour



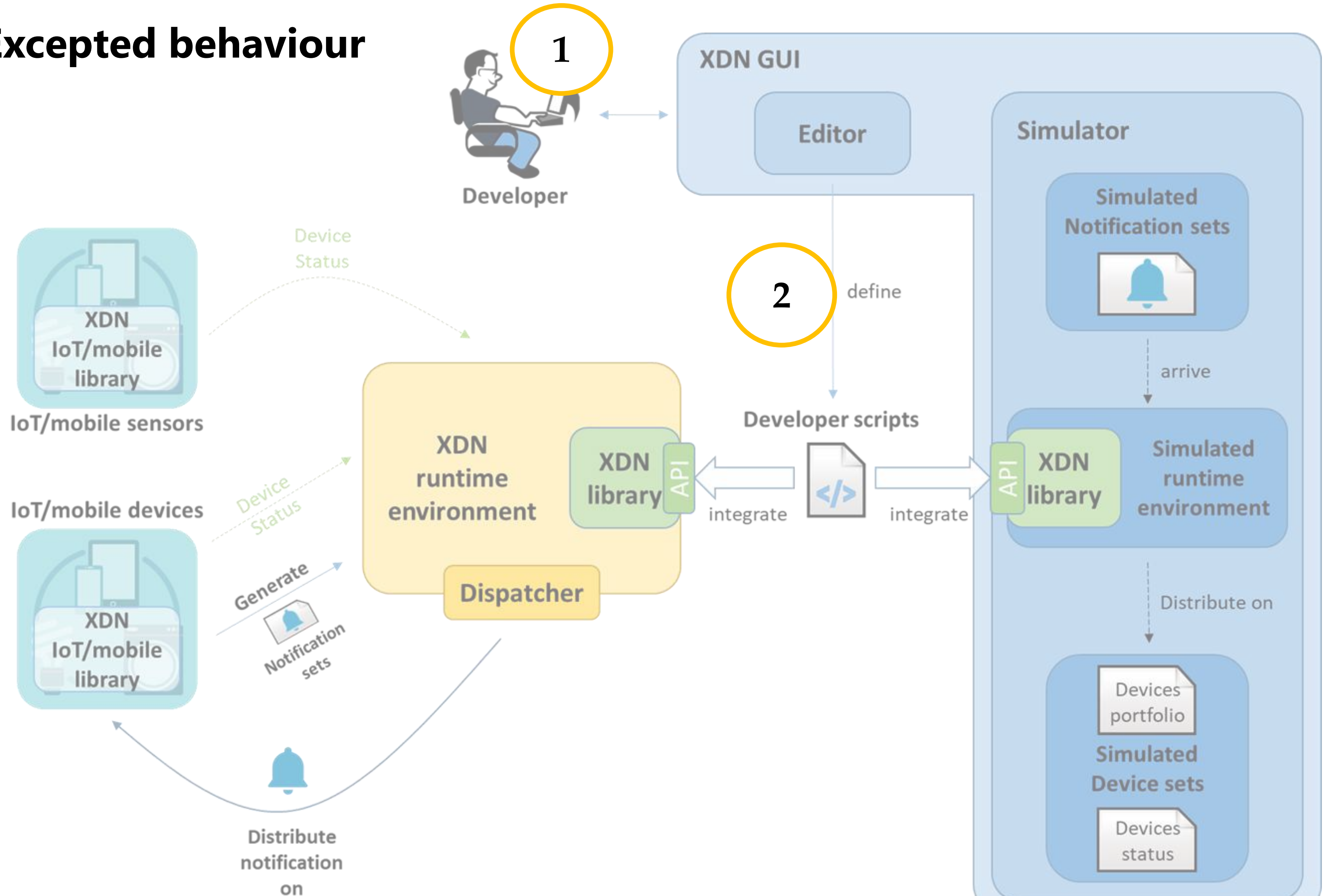
XDN: Architecture

Excepted behaviour



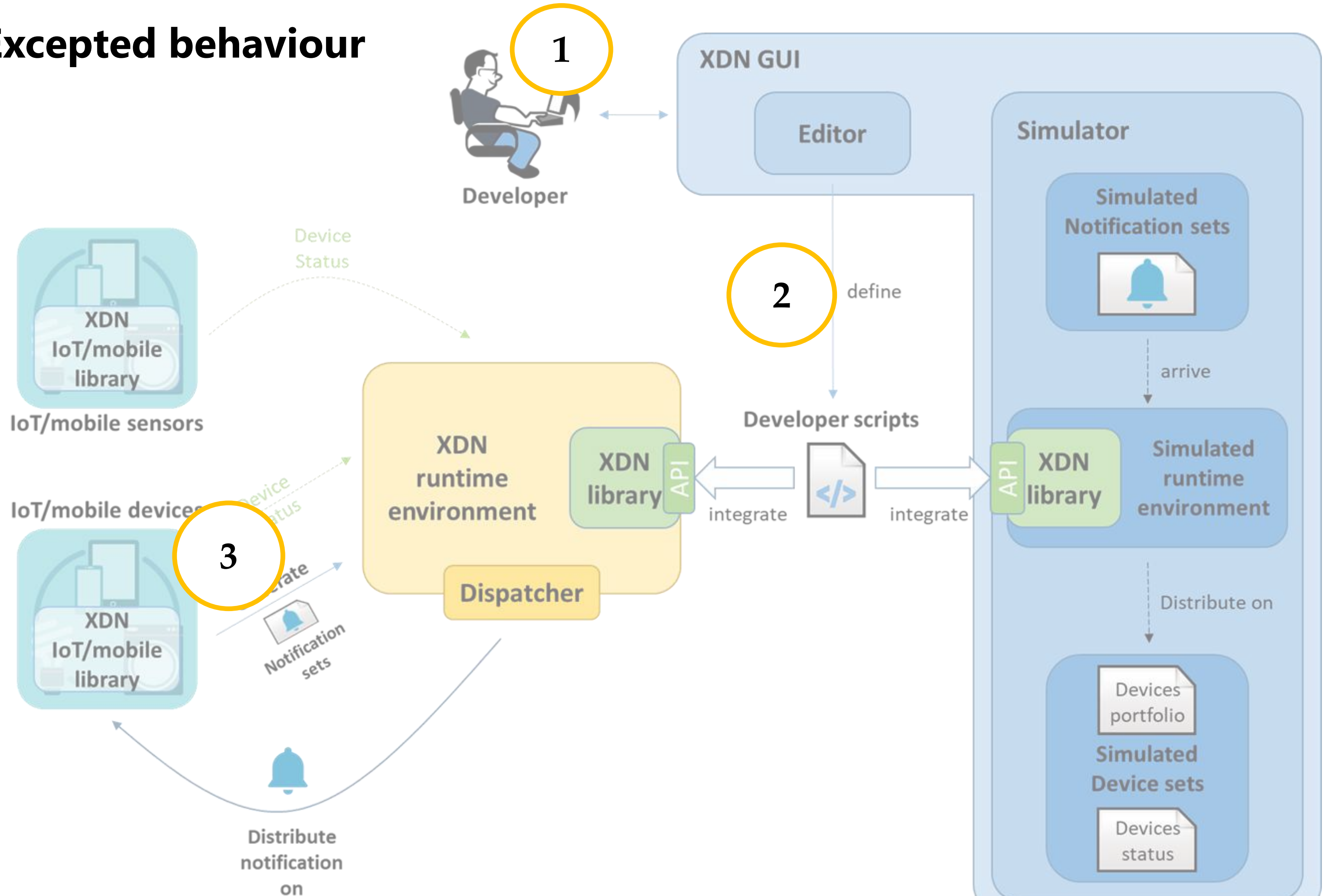
XDN: Architecture

Excepted behaviour



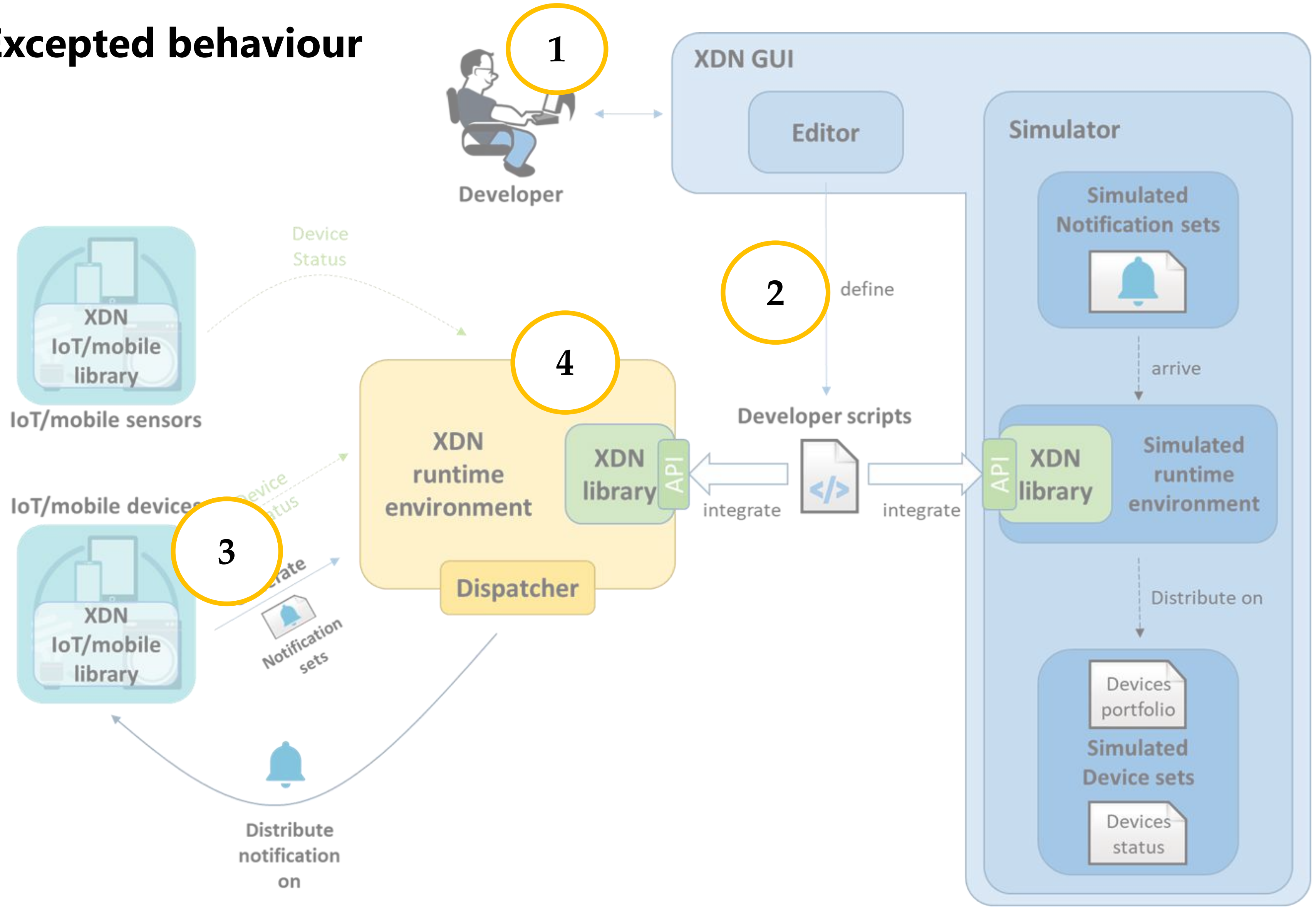
XDN: Architecture

Excepted behaviour



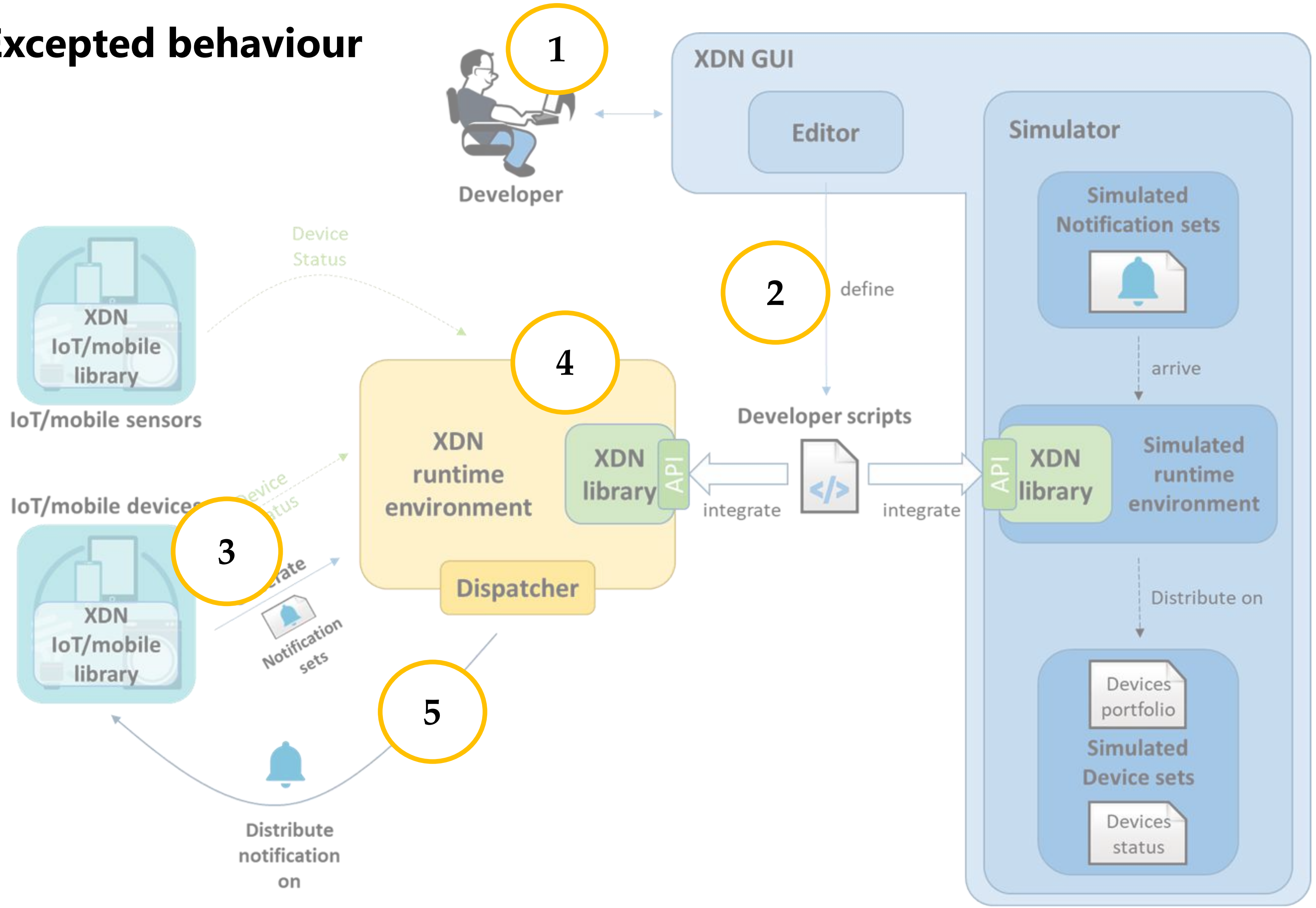
XDN: Architecture

Excepted behaviour



XDN: Architecture

Excepted behaviour



XDN: first prototype

2 components were developed:

1. The **XDN library (API)**
2. The **XDN GUI**

Tests with 12 volunteers (11 males and 1 female)

Aims:

- **demonstrate the fulfillment of all the requirements**
- **collect** a **feedback** about APIs and GUI

Each **user tasks**:

- modify an existing notification strategy
- develop a new notification strategy respecting some given requirements

Volunteers' main requirement:

- Previous experience with JavaScript

Used tools

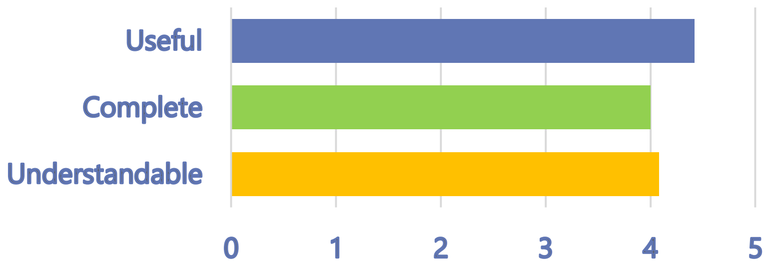
XDN: first prototype

Results:

7 participants over 12 were able to complete all the tasks in the required time.

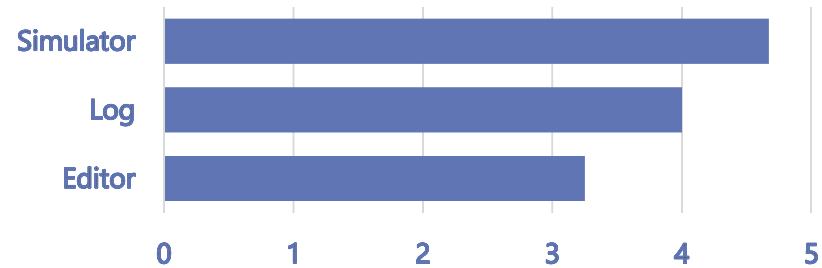
User feedback: **survey** (from 0 to 5)

XDN Library (API)



XDN GUI

Is it **Useful**?



XDN framework in general

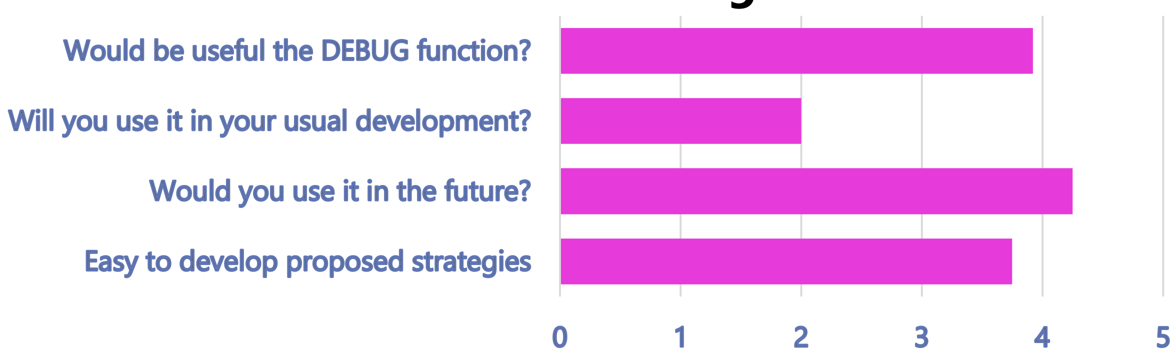


Table 3.6 - Final survey proposed to user

XDN: first prototype

Results:

7 participants over 12 were able to complete all the tasks in the required time

XDN Main outcome

- **Efficacy** of the proposed solution to **enhance developers** that want to design, develop and test their own notification strategies

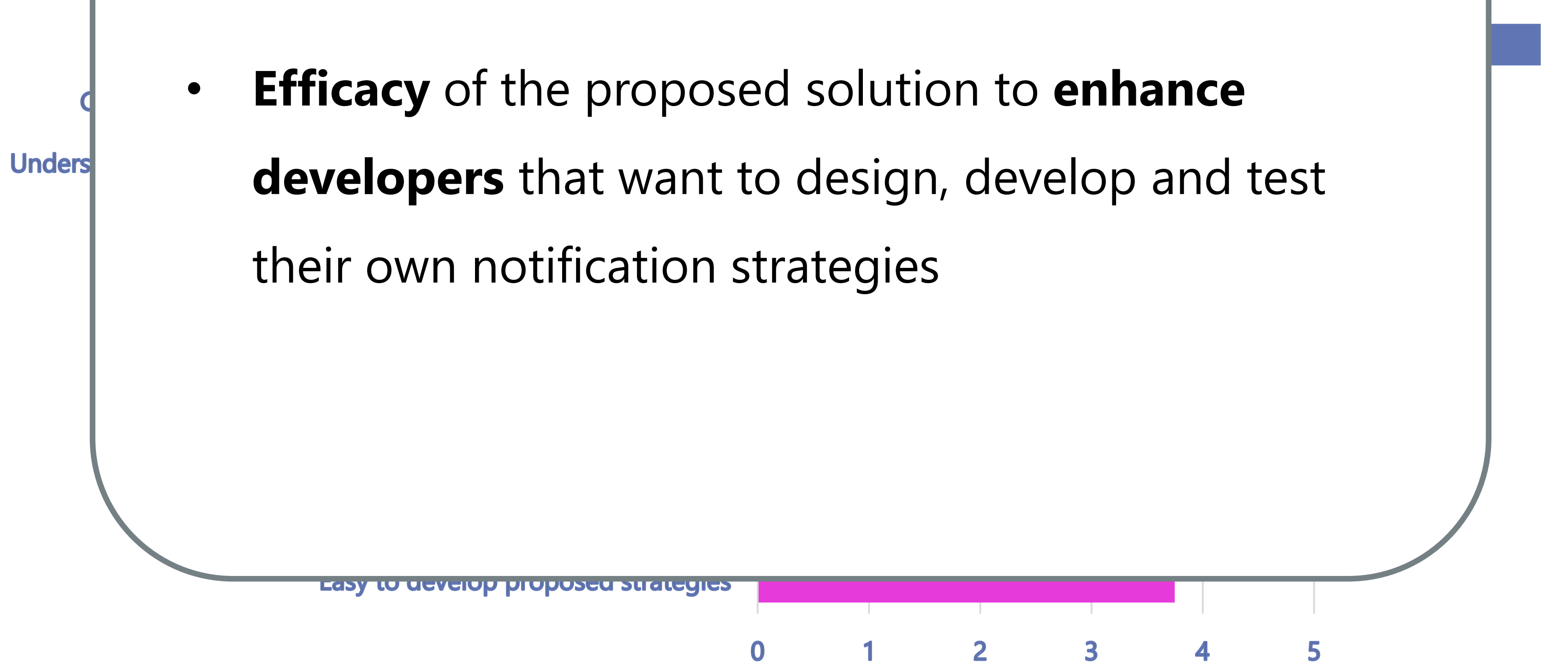


Table 3.6 - Final survey proposed to user

Thesis Conclusions

Main Problem: Overwhelming notifications

Our proposals:

1. **SNS** that acts at the **distribution** level and fosters **ML algorithms** (autonomous system that directly influences **end-users**)
2. **XDN** that acts at the **design** level and fosters **cross-device approach** (framework for **developers**)

Main outcome:

- **Feasibility** of the proposed approaches was demonstrated
- **Efficacy** of the **proposed solutions** to **enhance**
    - **user experience** with notifications
    - **developers** support in designing, developing and testing their own notification strategies also exploiting the **cross-device approach**
- **Efficacy** of the **user-centered design** methodology in notification domain

Publications during the Ph.D.

2018

- *Corno, F and De Russis, L. and Marcelli, A. and Montanaro, T. . **An Unsupervised and Non-Invasive Model for Predicting Network Resource Demands**. In IEEE Internet of Things Journal.*

- *Cagliero, L. and De Russis, L. and Farinetti, L and Montanaro, T. . **Improving the effectiveness of SQL learning practice: a data-driven approach**. In 2018 IEEE 42nd Annual Computer Software and Applications Conference (COMPSAC).*

2017

- *Corno F.; De Russis L.; Montanaro T.- **XDN: Cross-Device Framework for Custom Notifications Management** - In: The 9th ACM SIGCHI Symposium on Engineering Interactive Computing Systems, Lisbon (Portugal), June 26-29, 2017. (In Press)*

- *Corno, Fulvio; Montanaro, Teodoro; Migliore, Carmelo; Castrogiovanni, Pino - **SmartBike: an IoT Crowd Sensing Platform for Monitoring City Air Pollution**. In: INTERNATIONAL JOURNAL OF ELECTRICAL AND COMPUTER ENGINEERING (IJECE, ISSN: 2088-8708, a **SCOPUS** indexed Journal - Q2), vol. 7 n. 6. (In Press)*

Publications during the Ph.D.

2016

- *Corno F., De Russis L., Montanaro T. -* ***Estimate User Meaningful Places through Low-Energy Mobile Sensing****. In: SMC 2016: IEEE International Conference on Systems, Man, and Cybernetics, Budapest, 9-12 October, 2016.*

- *Ghajargar M., Zenezini G., and Montanaro T. -* ***Home delivery services: innovations and emerging needs****. In: 8th IFAC Conference on Manufacturing Modelling, Management and Control MIM 2016, Troyes, France, 28—30 June 2016. pp. 1371-1376*

2015

- *Corno F.; De Russis L.; Montanaro T.; Castrogiovanni P. -* ***IoT Meets Exhibition Areas: a Modular Architecture to Improve Proximity Interactions****. In: FiCloud 2015: The 3rd International Conference on Future Internet of Things and Cloud, Roma, 24-26 August, 2015. pp. 293-300*

- *Corno, Fulvio; De Russis, Luigi; Montanaro, Teodoro -* ***A Context and User Aware Smart Notification System****. In: IEEE 2nd World Forum on Internet of Things (WF-IoT), Milan, Italy, 14-16 December 2015. pp. 645-651*

- *Montanaro, Teodoro (2015) -* ***SWARM Joint Open Lab Politecnico Di Torino, Italy****. In: CROSSROADS, vol. 22 n. 2, pp. 70-71. - ISSN 1528-4972*

THANK YOU FOR YOUR ATTENTION

Summary of contributions

Main Problem: Overwhelming notifications

Our proposals:

1. **SNS** acts at the **distribution** level and fosters **ML algorithms** (autonomous system that directly influences **end-users**)
   - Decision Maker
   - Collectors
   - Context Analysis
2. **XDN** acts at the **design** level and fosters **cross-device approach** (framework for **developers**)
   - XDN library
   - XDN GUI
   - XDN Runtime Environment
   - XDN IoT/Mobile library