A Privacy-Centered System Model for Smart Connected Homes

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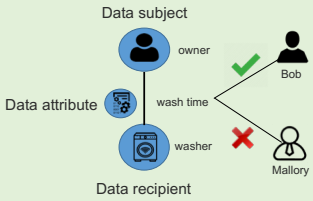
INTRODUCTION

- The home is the place where intimacy and reserve are expected.
- Internet-connected devices are resulting in potential for abuse, misuse, and appropriation of user data.
- This paper: **Proposes a model that can be used for the systematic identification and modeling of privacy threats affecting smart homes.**
- **Problems with existing works….**
  - **Narrow scope:** Challenging to apply to realistic use-cases.
  - **Model shortage:** Lack of a standard model that focuses on the home.
  - **Shallow analysis:** Privacy threats are identified without any formal basis.

BACKGROUND

- Privacy is defined as the appropriateness of information flows.*



- Leveraging the theory of Contextual Integrity* as an overarching framework.

* Nissenbaum, Helen. "Privacy as contextual integrity." *Wash. L. Rev.* 79 (2004): 119.

METHODS

- Blackbox modelling and abstract notation for describing the smart connected home.
- High-order logic and functions are created for the identification of privacy threats.
- The identification of threats is based on Ziegeldorf et al.+ work on information privacy.

+ Ziegeldorf, Jan Henrik, Oscar Garcia Morchon, and Klaus Wehrle. "Privacy in the Internet of Things: threats and challenges." *Security and Communication Networks* 7.12 (2014): 2728-2742.

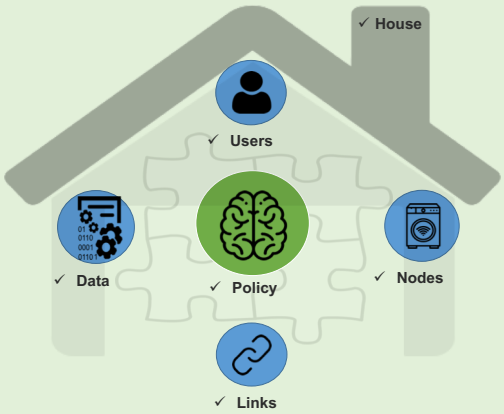
HOME AND PRIVACY THREATS

- The smart connected home is represented as a 6-tuple system:
  - *H*, House, is the physical building which the residents inhabit.
  - *N*, Nodes, is a set of physical components of the smart connected home space.
  - *U*, Users, is a set of human users interacting with the smart connected home.
  - *L*, Links, is a set of communication channels between the nodes and users.
  - *D*, Data, is a set of data being collected and processed by the smart connected home setup.
  - *P*, Policy, is a set of rules describing how data are transmitted between the different entities.
- For the privacy threats, we created 6 primitives and 7 logical formulas to support their identification, given a particular smart home configuration.

Primitives/ Formulas	$\Phi^{d_x}_{d_i}, \theta^{d_x}_{d_i}, \gamma^n, perms^u_{d_i}, read^l_{d_i}, write^l_{d_i}$
	$\stackrel{def}{=} \forall p \in P, \exists\ (dp_i <> \emptyset) \wedge (\Phi^{d_x}_{dp_i.d_i} = \texttt{true})$
	$\stackrel{def}{=} \exists\ (l \in L) \wedge (\Phi^{d_x}_{d_i} = \texttt{true}) \wedge write^l_{d_i}$
	$\stackrel{def}{=} \forall p \in P, \exists\ (dp_i <> \emptyset) \wedge (\theta^{d_x}_{dp_i.d_i} = \texttt{true})$
	$\stackrel{def}{=} \forall l_i, l_e \in L \wedge (l_i <> l_e) \wedge (read^l_{d_{i1}} \wedge read^l_{d_{i2}} \implies read^{l_e}_{d_{new}}) \wedge (read \notin perms^u_{d_{new}})$
	$\stackrel{def}{=} \exists\ (l \in L) \wedge (u \in U) \wedge read^l_{d_i} \wedge (read \notin perms^u_{d_i})$
	$\stackrel{def}{=} \exists\ (n \in N) \wedge (\gamma^n = \texttt{true})$
	$\stackrel{def}{=} \exists\ (l \in L) \wedge (u \in U) \wedge write^l_{d_i} \wedge (write \notin perms^u_{d_i})$

PRIVACY-CENTERED SYSTEM MODEL

- A graphical illustration of the proposed model alongside the privacy threats that it can identify.



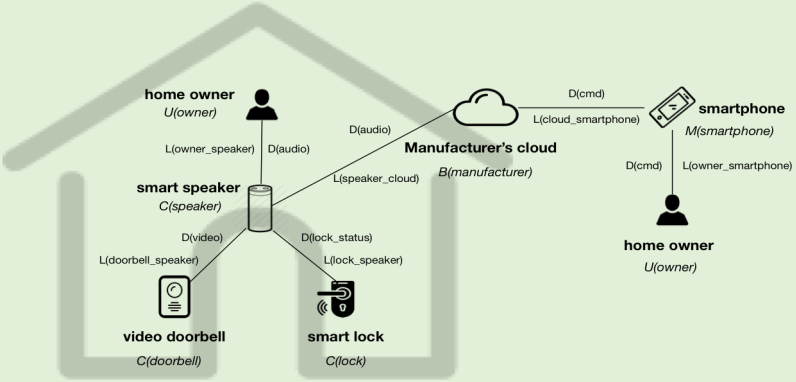
- ✓ Support for the automatic detection of privacy threats through logical formulas.
- ✓ Device and service agnostic.
- ✓ Model is scalable and extensible.

Threat does not exist | Threat is a potential future threat | Threat is present

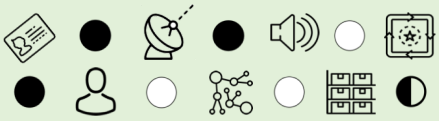
- Identification
- Profiling
- Localization and tracking
- Linkage
- Privacy-violating interaction and presentation
- Inventory attacks
- Lifecycle transitions

AMBIENT-ASSISTED LIVING USE-CASE

- An instantiation of the privacy-centered system model in a setup involving the home owner who can unlock a door using voice as input, and remotely through a smartphone.



- House, $H = \{house\}$
- Nodes, $N = \{doorbell, lock;\ speaker, manufacturer, smartphone\}$
  $C(speaker).capabilities = \{gateway, storage, processing, interaction\}$
  $B(manufacturer) = cloud$
- Users, $U = \{owner\}$
- Links, $L = \{doorbell\_speaker, lock\_speaker,\ speaker\_cloud,\ cloud\_smartphone,\ owner\_smartphone,\ owner\_speaker\}$
- Data, $D = \{(lock\_status,\ system,\ lock\ open/close,\ indefinite),\ (cmd, system, application\ command, purpose),\ (video, visitor, video\ of\ guest(s), purpose),\ (audio, owner, voice\ interaction, purpose)\}$
- Policy, $P =$ {(*doorbell_speaker*, {(*video*, {*read*})}, *doorbell, speaker*,∅),
  (*lock_speaker*, {(*lock_status*,{*read*})}, *lock, speaker*,∅),
  (*speaker_cloud*, {(*audio*, {*read*})}, *speaker, manufacturer,*
  Time = {8 :00 − 24:00} ∧ *Location* = {*house*}),
  (*cloud_smartphone*, {(*cmd*, {*read*})}, *smartphone, manufacturer*,∅),
  (*owner_smartphone*, {(*cmd*, {*read*})}, *owner, smartphone*,∅),
  (*owner_speaker*, {(*audio*, {*read*})}, *owner, speaker*,∅)}



CONCLUSIONS AND FUTURE WORK

- IoT technologies deployed inside the home challenge the long-held notion that the home is a private, protected, and intimate place.
- We contributed in adding more more transparency about risks emerging out of smart homes.
- Our privacy-centered system model helps in the identification and modelling of privacy threats.
- For future work:
  - Evaluate the completeness of the proposed model through empirical studies.
  - Express the system model using a formal specification language.
  - Leverage the model for performing quantitative risk analysis.

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