Internet das Coisas

Alessandro Copetti
e-mail: alessandro.copetti@gmail.com

Tópicos

- Contexto de IoT
- Tecnologias de comunicação
- CoAP
- MQTT
- IoT e Cloud

Principal referência:

Artigo: **Internet of things: A survey on enabling technologies, protocols, and applications.**

Autores: Al-Fuqaha, A., Guizani, M., Mohammadi, M., Aledhari, M., & Ayyash, M. (2015).

Publicado em: IEEE Communications Surveys & Tutorials, 17(4), 2347-2376.

Contexto

- Internet das Coisas (Internet of things - IoT) está sendo possível com as inovações em:
  - RFID
  - Sensores inteligentes
    - com colaboração entre eles
  - Tecnologias de comunicação
  - Protocolos Internet

(Al-Fuqaha et al., 2015)

Contexto

- Pervasive Computing
- Mobile Computing
- Context Aware Computing
- Industry 4.0
- Ubiquitous Computing
- Wireless Sensor Networks
- Body Area Networks
- Embedded Systems
- Cyber Physical Systems

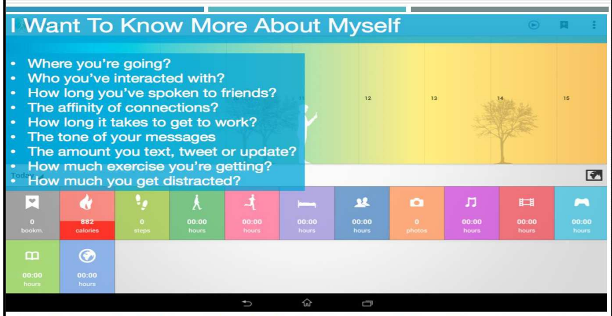
Contexto

- No. objetos para se conectar a Internet
  - recursos escassos: bateria, armazenamento, memória, processamento, interface, rede
- Segurança e privacidade devido a inerente heterogeneidade e a capacidade para monitorar e controlar objetos físicos
- Gerenciamento e monitoramento de IoT para assegurar a entrega de serviços de alta qualidade a um custo eficiente

(Al-Fuqaha et al., 2015)

How Well Do I Sleep?

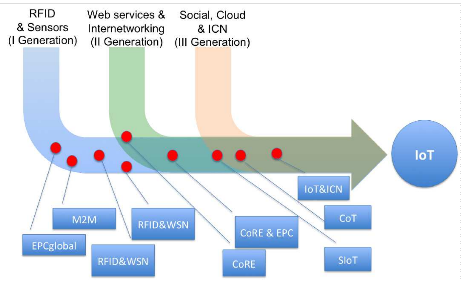
(Al-Fuqaha., 2018)



Can Internet of Things (IOT) Help Us To Know More About Ourselves?

(Al-Fuqaha., 2018)

Evolução da IoT



(Atzori et al., 2017)

Gerações IoT

Generation	*Technological fields*	*Major objectives*	*Relevat standards*
I	**Tagged objects**	To uniquely identify objects through appropriate naming and architecture for the retrieval of objects' associated information	EPCglobal
	Machine-to-Machine (M2M)	To define a reference architecture for machine-to-machine communications	oneM2M, ITU-T FS M2M
	Integration RFID with WSN	To seamless combine data coming from RFID tags with data generated by sensors connected through WSNs	*Missing*
II	**Internetworking**	To allow constrained devices to adopt the TCP/IP protocols for a seamless integration in the Internet	IETF 6LoWPAN, ROLL RPL, IEEE 802.15.4
	Web of Things	To allow constrained devices to take part to web communications	IETF CoAP, OASIS DPWS
	Social network services	To allow people to share data generated by their smart objects with people they know and trust, leveraging the existing human social networks services	*Missing*

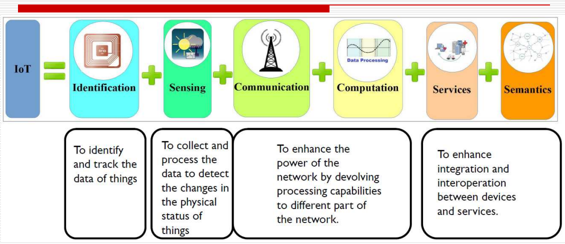
(Atzori et al., 2017)

Gerações IoT

III	**Social Internet of Things**	To make objects able to participate in communities of objects, to create groups of interest, and to take collaborative actions with the objective to facilitate service and information discovery	*Missing*
	Semantic	To describe the features of the IoT objects to foster systems interoperability	W3C SSN
	Future Internet	To introduce the Information Centric Networking feature into the IoT world so as to introduce content centric-driven rather than host-driven communications	IETF ICNRG
	Cloud	To empower objects with storage, communications and processing capabilities coming from the cloud	*Missing*
	Evolved RFID-IoT integration	To facilitate the integration of the RFIDs into the IoT applications	*Missing*

(Atzori et al., 2017)

IoT - elementos



(Al-Fuqaha et al., 2015)

IoT - elementos

IoT Elements		Samples
Identification	Naming	EPC, uCode
	Addressing	IPv4, IPv6
Sensing		Smart Sensors, Wearable sensing devices, Embedded sensors, Actuators, RFID tag
Communication		RFID, NFC, UWB, Bluetooth, BLE, IEEE 802.15.4, Z-Wave, WiFi, WiFiDirect, , LTE-A
Computation	Hardware	SmartThings, Arduino, Phidgets, Intel Galileo, Raspberry Pi, Gadgeteer, BeagleBone, Cubieboard, Smart Phones
	Software	OS (Contiki, TinyOS, LiteOS, Riot OS, Android); Cloud (Nimbits, Hadoop, etc.)
Service		Identity-related (shipping), Information Aggregation (smart grid), Collaborative-Aware (smart home), Ubiquitous (smart city)
Semantic		RDF, OWL, EXI

Efficient XML Interchange (EXI) is a binary XML format for exchange of data on a computer network – 2011.

(Al-Fuqaha et al., 2015)

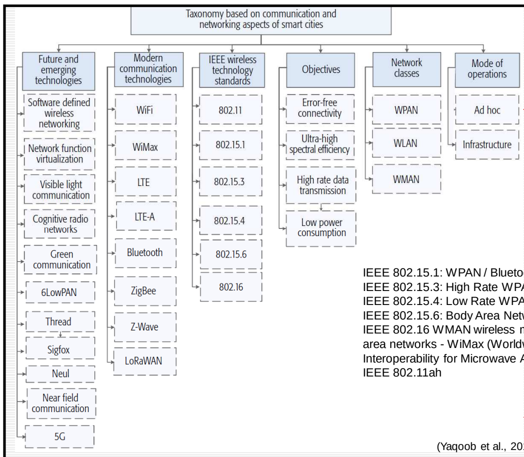
Tecnologias de Comunicação

Communication technology	Standard/ governing bodies	Frequency	Range (approximately)	Data rates	Topology
Bluetooth	IEEE 802.15.1	2.4 GHz	1–100 m	1 Mb/s	Point-to-point
Z-Wave	–	900 MHz	100 m	9.6–100 kb/s	Star, cluster, mesh
ZigBee	IEEE 802.15.4	2.4 GHz	10–20 m	25 0kb/s	Mesh
LoRaWAN	LoRa Alliance	867–869 MHz (Euorpe)	2–5 km	290 b/s–50 kb/s	Star
WiFi	IEEE 802.11 (a/b/g/n)	2.4 GHz, 3.6 GHz, 4.9 GHz, 5 GHz, 5.9 GHz	100 m	1–5 4Mb/s	Star
WiMAX	3GPP	3.5 GHz	50 km	75 Mb/s	Point-to-multipoint, mesh
LTE	3GPP	2.5 GHz, 5 GHz, 10 GHz	30 km	30 0Mb/s(DL), 75 Mb/s(UL)	Star
LTE-A	3GPP	2.5 GHz, 5 GHz, 10 GHz, 15 GHz, 20 GHz	30Km	1Gb(DL), 500Mb/s(UL)	Point-to-point

(Yaqoob et al., 2017)

3GPP 3rd Generation Partnership Project (www.3gpp.org)

- "The original scope of 3GPP (1998) was to produce Technical Specifications for a 3G Mobile System based on evolved GSM (Global System for Mobile communication) core networks and the radio access technologies"
- Gerações de sistemas móveis:
  - 1G: analógico (1980)
  - 2G: digital (1990): GSM/GPRS & EDGE, CDMAOne
  - 3G: GSM, GPRS, EDGE, UMTS, HSPA
  - 3G/4G: LTE-Advanced
  - 5G: vel.>10Gb/s; >dispositivos conectados (2019)



IEEE 802.15.1: WPAN / Bluetooth
IEEE 802.15.3: High Rate WPAN
IEEE 802.15.4: Low Rate WPAN
IEEE 802.15.6: Body Area Networks
IEEE 802.16 WMAN wireless metropolitan area networks - WiMax (Worldwide Interoperability for Microwave Access)
IEEE 802.11ah

(Yaqoob et al., 2017)

Low Power Wide Area Networks (LPWAN)

Table 1. Low Power Wide Area Radio Technologies for Internet of Things (IoT) Service.

	LoRa	SigFox	Wi-SUN	NB-IoT	LTE-M
Coverage	~11 km	~13 km	~5 km	~15 km	~11 km
Spectrum	800~900 MHz	800~900 MHz	900 MHz	700~900 MHz	700~900 MHz
Band	ISM/unlicensed	ISM/unlicensed	ISM/unlicensed	Cellular/licensed	Cellular/licensed
Bandwidth	125 KHz	0.1/0.6 KHz	0.1 KHz	200 KHz	20 MHz
Data Rate	~10 kbps	~100 bps	~300 kbps	150 kbps	~10 Mbps
TX Power	14 dBm	14/27 dBm	13/24 dBm	23/35 dBm	23 dBm
Roaming	N	N	N	Y	Y

(Moon, 2017)

IEEE 802.15.4

- Provê serviços de segurança, criptografia e autenticação, mas não garante QoS
- É a base para o protocolo ZigBee, oferecendo "low data rate services on power constrained devices"
- Para reduzir potenciais colisões, IEEE 802.15.4 MAC utiliza o protocolo CSMA/CA

(Al-Fuqaha et al., 2015) - ver Fuqaha-slides-IoT-rev3.pdf p. 61

IEEE 802.15.4

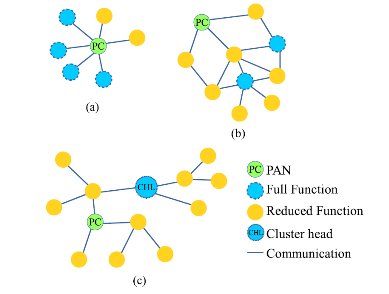


Fig. 20. IEEE 802.15.4 topologies [33]. (a) Star. (b) Peer-to-peer. (c) Cluster-tree.

Bluetooth Low-Energy (BLE)

- Rádio de curto alcance com uma quantidade mínima de energia para operar por um tempo mais longo comparado com prévias versões
- Alcance de cobertura (~100 metros) é 10 vezes do que o Bluetooth clássico e a latência é 15 vezes menor
- Comparado ao ZigBee, BLE é mais eficiente em termos de consumo de energia e a razão de energia de transmissão por bit transmitido

(Al-Fuqaha et al., 2015)

SOs usados em ambientes IoT

Operating System	Language Support	Minimum Memory (KB)	Event-based Programming	Multi-threading	Dynamic Memory
TinyOS	nesC	1	Yes	Partial	Yes
Contiki	C	2	Yes	Yes	Yes
LiteOS	C	4	Yes	Yes	Yes
Riot OS	C/C++	1.5	No	Yes	Yes
Android	Java	-	Yes	Yes	Yes

TinyOS: (2000)
Para rede de sensores
Últ versão 2012

Contiki: (2002)
Simulador Cooja; leve < 10k
http://www.contiki-os.org/

LiteOS:
Stankovic
Últ versão 2014

Riot OS: (2009)
arch e.g.: ARM Cortex; IoT protoc
http://www.riot-os.org/

(Al-Fuqaha et al., 2015) - ver ref. [8] dos artigos

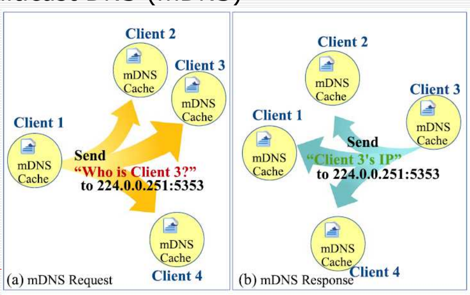
Esforços de padronização na IoT

Application Protocol		DDS	CoAP	AMQP	MQTT	MQTT-SN	XMPP	HTTP REST
Service Discovery		mDNS			DNS-SD			
Infrastructure Protocols	Routing Protocol	RPL						
	Network Layer	6LoWPAN				IPv4/IPv6		
	Link Layer	IEEE 802.15.4						
	Physical/ Device Layer	LTE-A	EPCglobal		IEEE 802.15.4	Z-Wave		
Influential Protocols		IEEE 1888.3, IPSec				IEEE 1905.1		

(Al-Fuqaha et al., 2015)

Descoberta de recursos

- Multicast DNS (mDNS)



Esforços de padronização na IoT

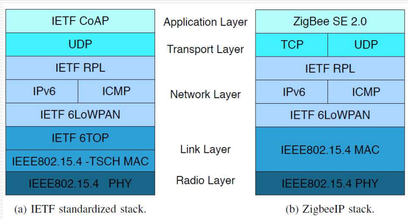
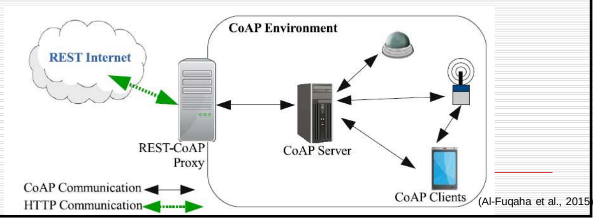


Fig. 1: Protocol stacks for the Internet of Things.

(Iova et al., 2016)

CoAP - *Constrained Application Protocol*

- Define um protocolo de transferência Web baseado no REpresentational State Transfer (REST) no topo do HTTP
  - usa UDP; msgs: GET, POST, PUT e DELETE



(Al-Fuqaha et al., 2015)

CoAP - mensagens

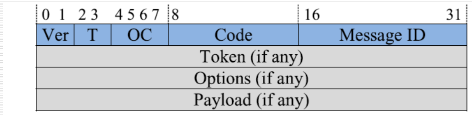


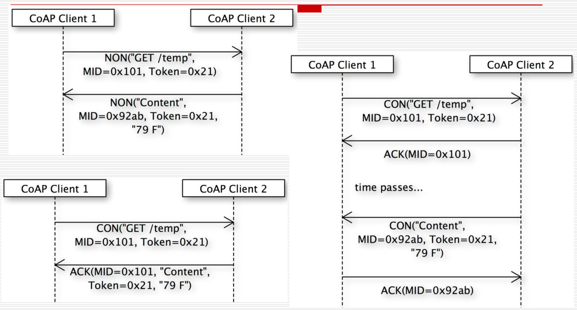
Fig. 7. CoAP message format.

T: tipo de transação; OC: option count

Token: correlaciona requisições e respostas

(Al-Fuqaha et al., 2015)

CoAP - mensagens

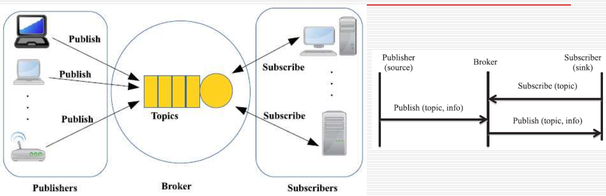


(http://programmingwithreason.com/article-iot-coap.html)

CoAP - características

- publish-subscribe IETF 02/07/2018
- descoberta de recursos
  - "Server utilizes well-known URI paths based on the web link fields in CoRE link format to provide resource discovery for the client"
    - Constrained RESTful Environments (CoRE) Link Format
- CoAP + datagram transport layer security (DTLS) garante integridade e confidencialidade na troca de msgs

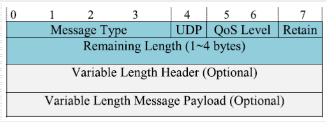
Message Queue Telemetry Transport (MQTT)



- usa TCP; 3 níveis de QoS:
  - At most once; At least once; Exactly once
- MQTT-SN usa UDP

http://docs.oasis-open.org/mqtt/mqtt/v3.1.1/os/mqtt-v3.1.1-os.html

MQTT – formato das mensagens



- Tipos: connect, connack, publish, subscribe, ...
- DUP: msg duplicada
- Retain: informa ao servidor para reter a última publicação e submetê-la a novos assinantes como primeira mensagem

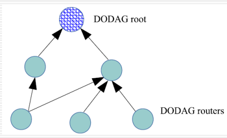
MQTT - https://iot.eclipse.org

- Eclipse Paho and Eclipse Mosquitto provide a client and broker implementation of the MQTT messaging protocol
- Mosquitto implements an MQTT server in C and Paho provides MQTT clients in a variety of language implementations, including C, C++, Java, JavaScript, Python, etc

---

- Outros protocolos de aplicação apresentados no artigo:
  - Extensible Messaging and Presence Protocol (XMPP)
  - Advanced Message Queuing Protocol (AMQP)
  - Data Distribution Service (DDS)
- Ex: https://thingspeak.com
  - escolha entre REST e MQTT

Routing Protocol for Low Power and Lossy Networks (RPL)



- Padronização IETF 2011
- O diagrama de roteamento é representado por um Destination Oriented Directed Acyclic Graph
- The packet contains the routing metric (e.g., link quality, residual energy) and an objective function used by each node to select the parents among its neighbors

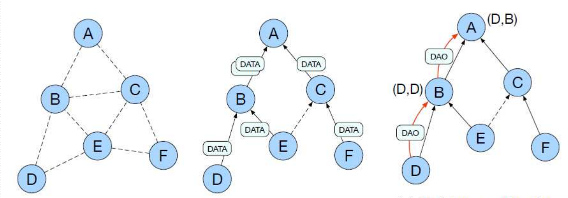
---

RPL - mensagens

- DODAG Information Object (DIO) which is used to keep the current rank (level) of the node, determine the distance of each node to the root based on some specific metrics, and choose the preferred parent path
- Destination Advertisement Object (DAO). RPL provides upward traffic as well as downward traffic support using DAO messages by which it unicasts destination information towards the selected parents
- DODAG Information Solicitation (DIS) which is used by a node to acquire DIO messages from a reachable adjacent node
- DAO Acknowledgment (DAO-Ack) which is a response to a DAO message and is sent by a DAO recipient node like a DAO parent or DODAG root

---

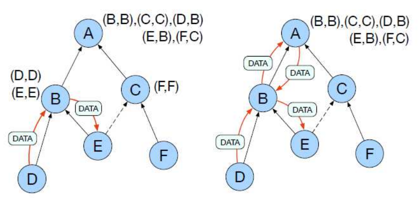
RPL - mensagens



(a) A sample wireless network. (b) Multipoint-to-point communication. (c) Point-to-multipoint route construction: storing mode.

(Iova et al., 2016)

RPL - mensagens



(d) Point-to-point communication: storing mode. (e) Point-to-point communication: non storing mode.

(Iova et al., 2016)

IPv6 over Low Power Wireless Personal Area Networks (6LowPAN)

- Necessidade de uma camada de adaptação para pacotes IPv6 em IEEE 802.15.4
  - tamanho do datagrama IPv6 1280 bytes e MTU do IEEE 802.15.4 é 127
- Compressão de cabeçalhos

(Al-Fuqaha et al., 2015)

IoT e Cloud

- Os recursos de armazenamento e computação da nuvem são a melhor escolha para a IoT armazenar e processar big data
- Características de plataformas de Cloud p/ IoT:
  - disponibilizar dados de sensores na Web
  - conectar dispositivos às aplicações de uma forma segura e em tempo real
  - prover solução Platform as a Service (PaaS) para IoT
  - facilitar a comunicação via HTTP(S), Sockets, MQTT…
  - integrar com outras plataformas e linguagens

(Al-Fuqaha et al., 2015)

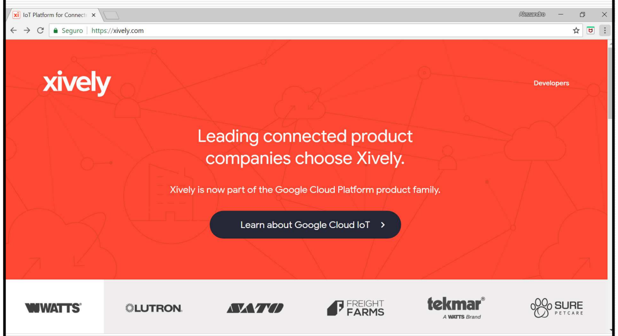
IoT e Cloud

IoT Cloud Platforms and Their Characteristics

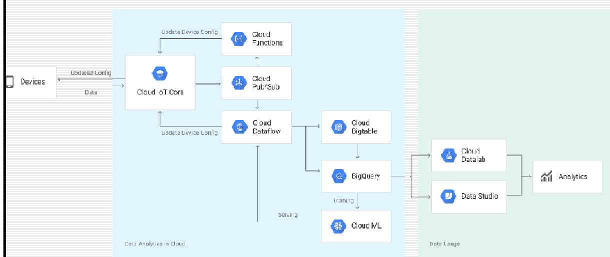
Platform	Gateway	Provision	Assurance	Billing	Application Protocol: REST	CoAP	XMPP	MQTT
Arkessa	-	+	+	-	+	-	-	+
Axeda	+	+	+	+	+	-	-	-
Etherios	+	+	+	-	+	-	-	-
LittleBits	-	-	-	-	+	-	-	-
NanoService	+	+	+	-	+	+	-	-
Nimbits	-	-	-	-	+	-	+	-
Ninja Blocks	+	-	-	-	+	-	-	-
OnePlatform	+	+	+	-	+	+	+	-
RealTime.io	+	+	-	-	+	-	-	-
SensorCloud	+	+	-	-	+	-	-	-
SmartThings	+	+	-	-	+	-	-	-
TempoDB	-	-	-	-	+	-	-	-
Thingworx	-	+	+	-	+	-	-	+
Xively	+	+	+	+	+	-	-	+

O que aconteceu com o melhor classificado?

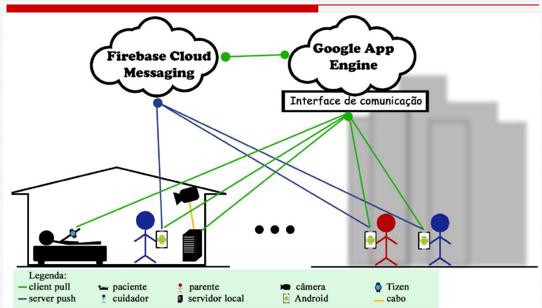
(Al-Fuqaha et al., 2015)



https://cloud.google.com/solutions/iot/



Google Cloud Plataform



Thiago Henriques Cunha. Infraestrutura de comunicação baseada em computação em nuvem para o monitoramento de pacientes. 2017. Trabalho de Conclusão de Curso. 42

Fog Computing

- a.k.a. cloudlets or edge computing, can act as a bridge between smart devices and large-scale cloud computing and storage services

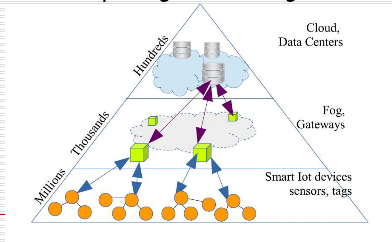


Fig. 24. The role of the cloud and fog resources in the delivery of IoT services

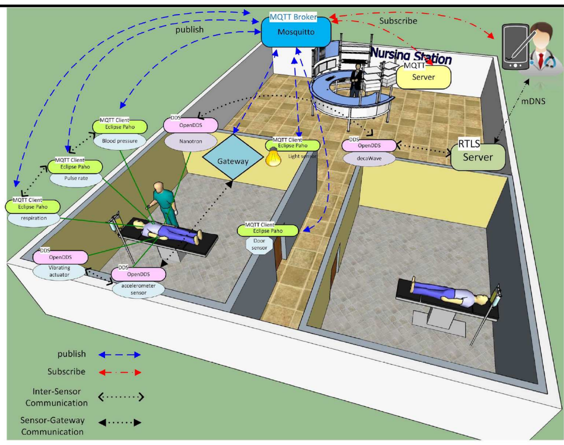
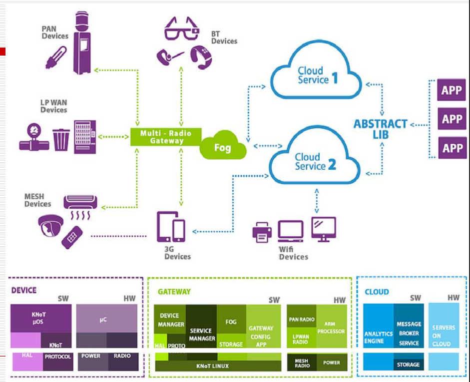


Fig. 28. The integration of IoT protocols in nursing scenario

iot.eclipse.org/

Creating a digital representation of a physical asset is often referred to as a 'digital twin'.

www.knot.cesar.org.br/



Referências

- Al-Fuqaha, A., Guizani, M., Mohammadi, M., Aledhari, M., & Ayyash, M. (2015). **Internet of things: A survey on enabling technologies, protocols, and applications**. IEEE Communications Surveys & Tutorials, 17(4), 2347-2376.
- Al-Fuqaha, Ala. (2018). **Internet of things. Applications & prospects.** Western Michigan University. Notas de aula.
- Yaqoob, I., Hashem, I. A. T., Mehmood, Y., Gani, A., Mokhtar, S., & Guizani, S. (2017). **Enabling communication technologies for smart cities.** IEEE Communications Magazine, 55(1), 112-120.

Referências

- Atzori, L., Iera, A., & Morabito, G. (2017). **Understanding the Internet of Things: definition, potentials, and societal role of a fast evolving paradigm**. Ad Hoc Networks, 56, 122-140.
- George Coulouris, Jean Dollimore e Tim Kindberg. **Sistemas Distribuídos - Conceitos e Projeto**, 5.ed., Bookman, 2013.
- Fettweis, G. P. (2014). **The tactile internet: applications and challenges**. Vehicular Technology Magazine, IEEE, 9(1), 64-70.

Referências

- Moon, B. (2017). **Dynamic Spectrum Access for Internet of Things Service in Cognitive Radio-Enabled LPWANs**. Sensors, 17(12), 2818.
- Iova, O., Picco, P., Istomin, T., & Kiraly, C. (2016). **RPL: The Routing Standard for the Internet of Things... Or Is It?**. IEEE Communications Magazine, 54(12), 16-22.
- Kurose, J., Ross, K. (2016) **Computer Networking: A Top-Down Approach**.

Referências

- **Associação Brasileira de Internet das Coisas**. http://abinc.org.br/
- **Constrained RESTful Environments (CoRE) Link Format**. https://tools.ietf.org/html/rfc6690
- **Publish-Subscribe Broker for the Constrained Application Protocol (CoAP)**. https://tools.ietf.org/html/draft-ietf-core-coap-pubsub-05

FIM

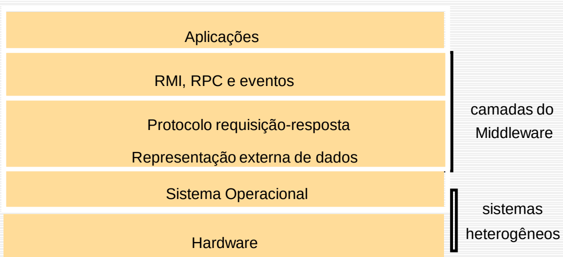
e-mail: alessandro.copetti@gmail.com

Electronic Product Code (EPC)

- Número de identificação único que é armazenado sobre uma etiqueta RFID
- EPCglobal é a organização responsável pelo desenvolvimento e padrões do EPC e RFID
- EPCs are classified into four types: 96-bit, 64-bit (I), 64-bit (II) and 64-bit (III). All types of 64-bit EPCs support about 16 000 companies with unique identities and cover 1 to 9 million types of products and 33 million serial numbers for each type. The 96-bit type supports about 268 million companies with unique identities, 16 million classes of products and 68 billion serial numbers for each class

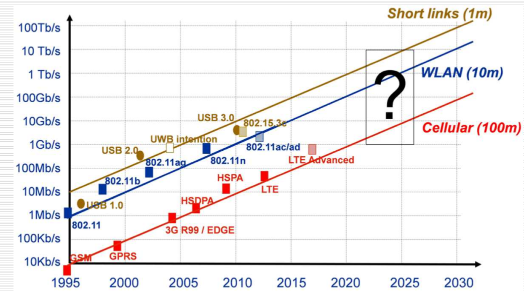
(Al-Fuqaha et al., 2015, p. 14)

Middleware



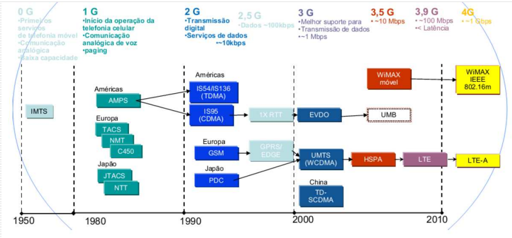
(Coulouris et al., 2013)

Tecnologias de redes sem fio



(Fettweis, 2014)

Tecnologias de redes celulares



Ana Gago, Nuno Cota, Performance Evaluation of Femtocells Usage on LTE, Procedia Technology, Volume 17, 2014, p. 683-691,

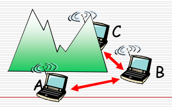
Tecnologias de redes celulares

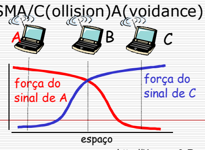
	Family	Technologies
1G	AMPS family	AMPS, TACS, ETACS
	Other	NMT, Hicap, Mobitex, DataTAC
2G	GSM/3GPP	GSM, CSD
	Cdma/3GPP2	CdmaOne (IS-95)
	Other	CDPD, iDEN, PDC, PHS
2G transitional (2.5G, 2.75G)	GSM/3GPP	HSCSD, GPRS, EDGE/EGPRS
	Cdma/3GPP2	CDMA2000 1xRTT (IS-2000)
	Other	WiDEN
3G (IMT-2000)	3GPP	UMTS (UTRAN), WCDMA-FDD, WCDMA-TDD, UTRA-TDD LCR (TD-SCDMA)
	3GPP2	CDMA2000 1xEV-DO (IS-856)
3G transitional (3.5G, 3.75G, 3.9G)	GSM/3GPP	HSDPA, HSUPA, HSPA+, LTE (E-UTRAN)
	Cdma/3GPP2	EV-DO Rev. A, EV-DO Rev. B
	Other	Mobile WiMAX (IEEE 802.16e-2005) · Flash-OFDM, IEEE 802.20
4G (IMT-Advanced)	GSM/3GPP	LTE Advanced
	Cdma/3GPP2	LTE Advanced
	Other	IEEE 802.16m (WiMAX)

http://thepump.jsi.com/the-evolution-of-mobile-infrastructure-and-cellular-networks/

IEEE 802.11: múltiplo acesso

- Evita colisões (CSMA/CA): dois ou mais nós transmitindo ao mesmo tempo
- 802.11: CSMA – "escuta" o meio antes de transmitir
  - para não colidir com outras transmissões em andamento
- 802.11: *não realiza detecção de colisão*!
  - Dificuldade de receber ("escutar" colisões) quando está transmitindo devido à fraqueza dos sinais recebidos (*fading*)
  - Não pode escutar todas as colisões: terminal escondido, *fading*
  - objetivo: *evitar colisões:* CSMA/C(ollision)A(voidance)





CDMA=Carrier Detection Multiple Access

http://Kurose & Ross, 2016)

Protocolo MAC do IEEE 802.11 : CSMA/CA

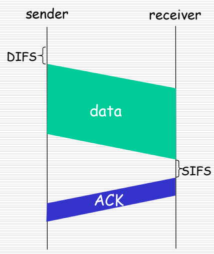
Emissor 802.11

1 se o canal estiver livre, espera um pequeno tempo (**DIFS**) e então transmite todo o quadro (não há detecção de colisão)

2 se o canal estiver ocupado então
   inicia um tempo de *backoff* aleatório
   faz contagem regressiva enquanto o canal estiver livre
   transmite qdo o tempo expirar
   se não chegar um ACK, aumenta o intervalo de *backoff* e repete o passo 2

Receptor 802.11

- se o quadro recebido estiver OK
   envia ACK depois de esperar um **SIFS** (o ACK é necessario devido ao problema do terminal escondido)



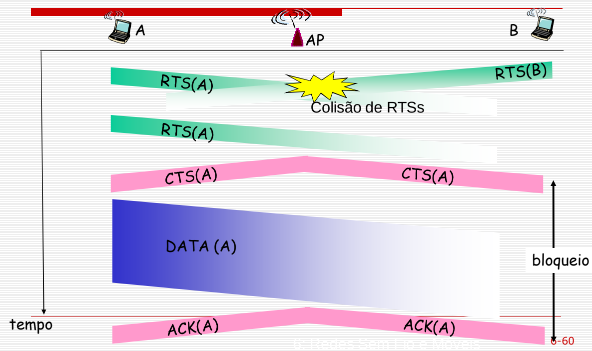
IEEE 802.11: Evitando colisões

ideia: permitir ao emissor reservar o canal ao invés de realizar um acesso aleatório dos quadros, evitando colisões de quadros longos

- Emissor primeiramente envia pequenos pacotes de controle request-to-send (RTS) para o AP usando o CSMA, mas que é ouvido por todas as estações ao seu alcance (inclusive o AP)
  - Obs: os pacotes RTS podem ainda colidir uns com os outros, mas como eles são pequenos, não causam longos atrasos
- AP envia um pct *clear-to-send* (CTS) para todas as estações que estão ao seu alcance, em resposta ao RTS
- Emissor transmite o quadro de dados
- Outras estações bloqueiam suas transmissões

Evita completamente as colisões de quadros de dados usando pequenos pcts de reserva!

Evitando Colisões: troca de RTS-CTS



Micro-location technologies

- Combining nanotron’s long-range Chirp radio location technology with DecaWave’s Ultra-Wide band location controllers