









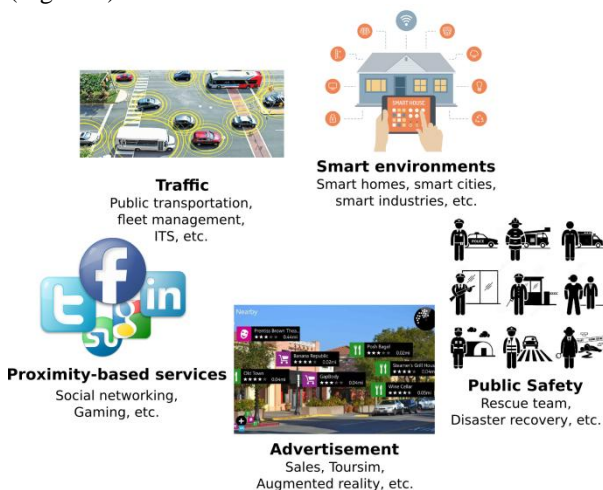




multimedia contents. Low-power radio technologies are not well suited to support these types of traffic, whereas cellular networks provide better performance for multimedia flows. However, accounting for the additional traffic generated by multimedia things, 5G shall include novel efficient techniques to meet both machine and human requirements, e.g., by leveraging on edge content caching and proximity content distribution.

#### 4. D2D Features as Enabling Factors for the future 5G Internet of Things

This section will browse through the main features of D2D communications with the potential to meet the IoT requirements discussed in the previous Sections. In particular, we will discuss key research contributions and highlight what has been done so far and what still remain to do for allowing IoT to take advantage of 5G system features. Indeed, proximity communications enabled by D2D communications represent a fertile ground for use cases where devices detect their vicinity and subsequently trigger different services, such as social interactions and gaming, advertisements, local information exchange, etc. (Figure 3).



**Figure 3.** Application scenarios for D2D-enhanced IoT environments.

By means of D2D discovery and communication functions, for instance, a user can find other near users to share data (multimedia content, environmental sensing, traffic condition, etc.), play interactive games, and so on. In applications for public safety support and emergency handling, devices can provide at least local connectivity in case of damage to the network infrastructure. Similarly, D2D communications may contribute to solve problems in emerging wireless communication scenarios, such as vehicle-to-vehicle (V2V) communication in Intelligent Traffic Systems (ITS) for traffic control/safety applications, or indirect indoor localization.

#### High data rate/Low delay

Short-range communications are typically characterized by higher throughput, lower delay and energy consumption when compared to long-range communications (clearly, this also depends on the D2D technology being adopted - see Table I in Section 2 - and on the scenario considered). The cited features are attractive for several application scenarios involving the support of *multimedia traffic over future IoT* systems. In particular, the authors of [40] consider base station controlled D2D communications to transmit cached video files in modern smartphones to other users through multiple D2D links over the same time/frequency resources within one cell. This leads to a huge increase in the spectral efficiency. Similarly, the higher data rate over D2D links is used for multimedia content dissemination in [41] [42], and for social-aware video multicasting in [43]. The possibility to cluster devices into groups connected through D2D links has also been widely investigated. Examples of applications exploiting D2D-based grouping are content sharing & dissemination (e.g., multicasting) [44] [45] [46] [47].

All the cited examples confirm that D2D can help, not only to meet the *group communication* requirements of multimedia IoT devices. It also allows to overcome typical *scalability* and *heterogeneity* issues of IoT. In fact, clustering the devices in a network may ease the handling of the expected large number of IoT devices with different capabilities and available communication technologies.

#### Low energy consumption communication

D2D communications guarantees a lower energy consumption [48] w.r.t. to classic transmission modalities, where devices communicate to the BS/AP. This feature makes D2D communications very attractive in the view of meeting the energy efficiency requirements of the IoT [49]. The lower energy consumption is a direct consequence of the lower transmission power necessary over short-range connections with neighboring devices. Furthermore, the channel quality achievable on short-range links is better than that on long-range links [50]. This implies that the active time for the device in data transmission and reception can be severely reduced, with a consequent energy consumption reduction, highly valuable to typical IoT things.

The idea of adopting short-range links for energy consumption reduction is not novel per-se, as several contributions in the literature investigate on this aspect. A very recent survey of cooperative content delivery techniques based on multiple wireless interfaces available on mobile devices has been presented in [51]. In particular, wireless cooperative networking, guaranteeing performance enhancements to handheld devices, is a well investigated research field. More specifically, cooperative content sharing have been in focus thanks to its easy implementation by modern multi-interface mobile devices and the many applications that can derive from it. According to this paradigm, users share portions of data

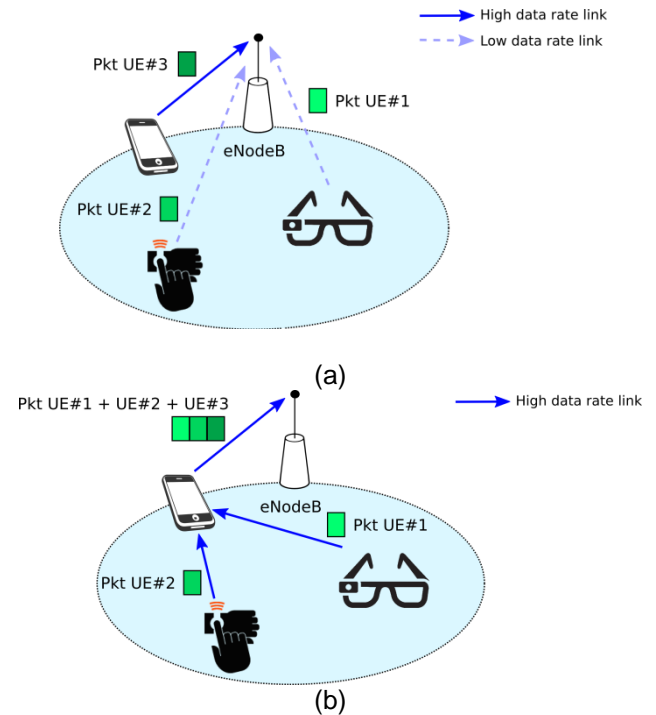
of common interest downloaded over costly long-range cellular links while exchanging the downloaded portions over short-range radio links. Significant research activity has been conducted to design strategies that simultaneously exploit the multiple radio interfaces of modern wireless devices and maximize the gains. As an example, the beneficial effects of integrating cellular and Wi-Fi networks are shown in [52] and [53]. The rewards of cooperation in terms of energy consumption and transfer delay are demonstrated also for cellular-Bluetooth scenarios [54]. Several other contributions investigated on the energy savings introduced by the synergistic use of multiple wireless network interfaces either located within the same device, or associated to several devices. At the same time, the short-range communication capability of modern wireless devices over unlicensed frequencies fostered the proliferation of a significant number of decentralized, spontaneous, and ubiquitous user interactions for content exchange.

When specifically considering the IoT scenarios, further constraints influencing the energy efficiency requirements shall be considered because exchanged data may vary greatly in size down to very small amounts in several scenarios. However, experiences made over the past years may be used to exploit at the best the assessed energy savings potentialities in the field of D2D communications.

### Aggregation

In IoT environments, most of the interactions are expected to take place locally, i.e., between physically co-located devices [5]. Where needed, end-to-end interactions can be addressed by smart ways of *aggregation*, where small data from several objects (close to each other, either with similar traffic patterns or belonging to the same IoT application) are collected by a terminal, namely the aggregator, which then forwards the aggregated data to the final destination. In these cases, the D2D paradigm is natively appropriated to support aggregation of data from neighboring nodes. An example of D2D aggregation in 5G environment is depicted in Figure 4, which shows the differences and the introduced benefits compared to legacy uplink data transmission.

Aggregation of industrial IoT (M2M) traffic is considered in [55], where D2D links are exploited to mitigate the capacity limitations of traditional large-scale transmissions (i.e., limited radio resources shared among a large set of users). Aiming at properly managing the D2D transmissions by a potentially large group of devices, the work defines a D2D-based access procedure: devices contend for access through an access reservation mechanism that allocates the slots of time for data transmission toward the aggregator. Following the packet aggregation over D2D links, the aggregator adds its own data and performs a transmission to the BS by adapting to the channel conditions the power, the transmission rate, and the actual amount of data to send.



**Figure 4.** Differences between: (a) legacy uplink, and (b) D2D-enhanced aggregation transmissions.

Moreover, novel solutions are needed to enable the efficient use of radio resources to convey small data packets in cellular environment (i.e., LTE/LTE-A), which are designed for supporting high data rates and big data sizes. As shown in [56], it is possible to improve the *communication* and the *energy efficiency* for small data transmission by using more robust Modulation and Coding Schemes (MCS) in the uplink, thus reducing data rate and lowering the transmission power. This simple approach guarantees better energy efficiency w.r.t. classic cellular-mode uplink transmissions. Building on this concept and on the possibility to aggregate data, D2D communication techniques may introduce further power savings. As proposed in [57], by smartly adapting the MCS of the aggregator node, radio resource utilization could be maximized depending on the total amount of data to send upon aggregation. If properly designed, this approach will allow low power transmissions both in intra-cluster communications over IoT D2D links, and in the uplink transmissions from the aggregator; thus reducing the overall energy consumption of the IoT devices.

The benefits introduced by D2D-based aggregation solutions motivate further work on this field. Possible trends are the definition of multi-criteria algorithms tailored to properly select the most suitable IoT device to act as aggregator. Further benefits are also expected by the design of enhanced D2D procedures aiming at boosting the performance (e.g., reducing the latency and the energy consumption) during the phase of data collection.



### Coverage extension

The possibility to exploit local D2D communications among devices supports coverage extension that may allow to reach nodes otherwise out of coverage of a cellular communication [58]. The idea of enabling D2D communications as a means for performing relaying in cellular networks was already addressed in ad hoc networks, e.g. in [59]. Nevertheless, the concept of allowing local D2D communications to (re)use cellular spectrum resources simultaneously with ongoing cellular traffic is relatively new [60] and coverage extension may be enhanced by relay-assisted multi-hop communications [61] [62]. In particular, network assisted two-hop D2D communications enhances the coverage and the energy efficiency of cellular networks and can be useful in providing national security and public safety services [63] [64] [65]. In a recent paper also multi-cell cellular systems have been modeled where UEs assist cell-edge users for relaying, and different approaches (amplify-and-forward and decode and-forward with either digital or analogue network coding) are compared to optimize the system performance [66]. Although the focus so far has been mainly on downlink services; uplink direction scenarios are of undoubted interest as witnessed by recent publications, such as [67], where relaying by smartphones is proposed to send out emergency messages from disconnected areas.

The mentioned researches are an undoubted good starting point to conceive and design mechanisms able to meet the *scalability* and *resiliency* requirements typical of IoT in future 5G scenarios. The simultaneous presence of highly mobile and stationary devices in the IoT may be particularly challenging. Mobile devices may get disconnected from the network as they move, which may lead to intermittent connectivity, thus causing unpredictable network topology changes that may benefit from D2D assistance from devices, as proposed for instance in [68].

### Multicast/Group communication

Researchers are currently active in the definition of multicast communications over D2D links in a similar way as it is known for classic cellular downlink transmissions. In particular, for D2D-based communications, direct multicast transmissions where the same packets from a UE are sent to multiple receivers are important in scenarios such as *Local file transfer/video streaming* (e.g., advertising messages), *Device discovery*, *Cluster head selection/coordination* (e.g., reaching out of coverage devices), *Group/broadcast communications* (e.g., for safety networks) [69]. Multicast transmission will support the deployment of IoT ecosystems and help in overcoming issues of *scalability*, *energy efficiency*, and efficient support of IoT *group communications*.

To efficiently support user diversity and serving more (or all) receivers in each multicast cluster, either retransmissions are required or more robust modulation and coding schemes should be used. Moreover, having a UE instead of the BS performing multicast, introduces

additional challenges due to limited capabilities of the UE. This issue is partially alleviated in cellular environments, where the UEs are assisted by the BS. Solutions for network-assisted multicast D2D communications have been proposed in research papers like [70] [71] and patenting activities [72]. These have paved the way to the future required activities specifically targeted to design similar methods performing well in IoT environments.

### D2D for Multi-RAT Heterogeneous Networks

Future IoT environments will foresee the presence of wireless networked devices employing multiple radio access technologies (RAT) to perform device-to-infrastructure and device-to-device communications; this will lead to heterogeneous multi-radio architectures. In this regard, a key aspect to investigate is how to deliver uniform connectivity and service experience in future 5G technologies. As an example, [73] investigate on the way a distributed unlicensed-band network (e.g., WiFi) takes advantage of the centralized control function residing in the cellular network (e.g., 3GPP LTE). In such an heterogeneous scenario, D2D communications may contribute to the proper management of devices. For instance, in [74] D2D communications allow to improve the performance of a converged network. In particular, a resource allocation scheme is proposed to perform mode selection and allocate resources in the involved networks, i.e., LTE-A cellular network and IEEE 802.11n WLANs.

A further example, more closely related to the IoT environment, is presented in [75], where the authors explore the opportunity of supporting low-rate low-power IoT traffic through D2D links with human-related devices (i.e., smartphones). In the proposed scheme, a multiple access channel for IoT devices is created by relying on underlying D2D transmissions from IoT terminals to a smartphone, which acts as a gateway for the IoT nodes. The key observation is that the low rate and the low power of the IoT traffic may allow the *gateway* to successfully decode the downlink transmissions from the BS to other devices, cancel them, and then attempt to decode the signal sent by IoT terminals via D2D links. In this scenario, heterogeneity is granted by the BS, which being aware about the presence of D2D links, can therefore adjust the power/rate of its transmissions to improve the IoT traffic reliability and to guarantee the simultaneous transmission of heterogeneous IoT/non-IoT traffic.

The IoT ecosystem can benefit from the use of D2D also in scenarios with multi-interface devices. In this case, the availability of different access technologies introduces the opportunity of properly selecting the best connection link. An example in [57] considers the pros and cons of D2D via LTE-Direct and WiFi-Direct by assuming different application requirements and network load conditions. This study outlines that LTE-Direct D2D technology is able to provide the most energy-efficient communication scheme when the number of user is relatively high (i.e., better scalability). However, WiFi-

Direct outperforms LTE-Direct in terms of energy efficiency in case of small amount of data. The results shown in [57] motivate the definition of algorithms that, according to IoT traffic patterns (e.g., packet size), network conditions (e.g., device load) and device capabilities (e.g., level of residual battery charge), properly select the most suitable D2D technology to guarantee traffic/network optimization in heterogeneous IoT scenarios.

### Higher cellular system capacity

The use of D2D communications has an overall positive impact also on the system capacity in cellular environments. The motivations behind this are mainly related to two factors: *data offloading* and *reuse gain*. Several studies in the literature investigated the positive impact of mobile data offloading [76] [77], that reduces the amount of data being carried over the cellular bands and, consequently, frees bandwidth for other users. However, the possibility to adopt underlay frequencies allows for data offloading solutions also on cellular radio resources [78] [60]. As for the *reuse gain*, the capacity of cellular networks is known to be strongly limited by interference at the receiver from communications ongoing on the same frequencies. Advanced methods for management of the interference between local D2D communications and with the BS (e.g., [58]), resource allocation in the cell (e.g., [79]) and mode selection techniques (e.g., [50]), have fostered frequency reuse techniques that tremendously increase the spectral efficiency and consequently the network capacity. Considering the future IoT applications, higher capacity systems will play in favor of *scalable* environments able to support also high capacity demanding *multimedia services* in densely deployed IoT scenarios.

### Concluding remarks

To summarize the analysis reported in this Section, in Figure 5 the mapping between IoT requirements and features of D2D communication for 5G is reported. A visual idea is reported on the contribution that D2D communications can give to meet the expected requirements of IoT in 5G systems.

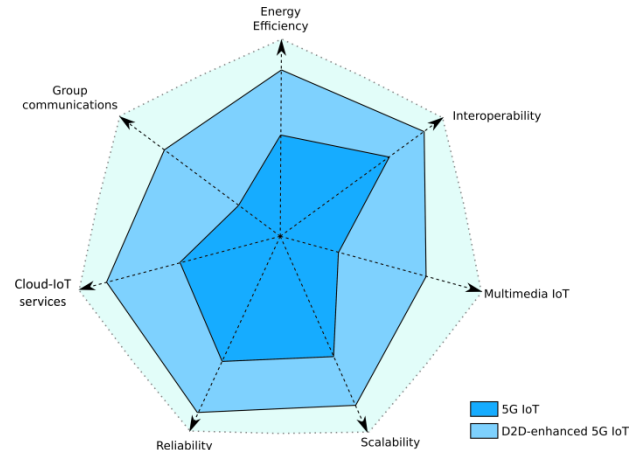


Figure 5. Target benefits for 5G IoT vs. D2D-enhanced 5G IoT.

## 5. Rethinking D2D for IoT in 5G Systems: Towards a Device-oriented Anything-as-a-Service Ecosystem

In the last years, the capabilities of mobile devices are constantly improving in terms of computation, storage, and networking capabilities. This has recently pushed research towards innovative networking paradigms that exploit the potentialities of the single devices. Among these, *local edge-clouds* [80] are proposed as a means to cooperatively share computing, storage and network capabilities among devices in close proximity. In this view, D2D communications may play a fundamental role to enable efficient exchange of data and services among mobile devices without necessarily relying on a cellular network. Besides, smart devices can provide virtualization of IoT objects. This would allow to include also resource constrained wearable sensors and their relevant functionalities in the local mobile clouds [81]. Nonetheless, infrastructure-less mobile cloud computing solutions present various obstacles towards an effective deployment, such as complex distributed management, weak authentication, and others. The network provider is expected to still play a key role by offering appropriate orchestration functionalities in a new networking landscape where the border between infrastructure and devices becomes even more blurred. Related to this, the METIS project has proposed a new concept of radio access network, the so-called RAN 2.0, where end-user devices can be in charge of network infrastructure nodes to provide *seamless connectivity* [82]. However, supporting ubiquitous networking only represents the first step towards a complete integration of the IoT into next-generation cellular systems.

By leveraging on virtualization, telco providers can indeed integrate heterogeneous systems into a unified service environment, which facilitates the development and execution of highly integrated and distributed IoT

applications. According to this vision, 5G should not be considered as a straightforward evolution of the current 4G network, but as a novel framework to enable the so-called “*Anything-as-a-Service*” paradigm [83], where also end-user devices can be directly exploited to provide “any type of service”. This solution allows to go beyond the concepts of Cloudlet and Fog architectures. Telco providers (*i*), on the one hand, are relieved of the financial costs related to the deployment of a large number of micro data centers (e.g., femtoclouds [84]) located very close to the customers, and, (*ii*) on the other hand, are evolving into ubiquitous service providers, by maintaining control, authentication and coordination functions, whereas delegating task execution to end-user devices. According to their capabilities, IoT objects will offer manifold services, ranging from computation to storage, from sensing and actuation to networking where D2D communication will be the core technology to provide the requested flexible interactions among end-user devices.

To enable the envisaged framework, great efforts are required in the next future to enhance the current network-oriented 3GPP ProSe by integrating functionalities for application service delivery. In this direction, softwarization and virtualization may come in handy to realize the view where devices, by acting as small-cells, become “active” units of 3GPP networks. In particular, ProSe discovery could be enriched to provide registration of both services offered by devices, and application requests of end-users, which will operate as *prosumers* of data and services. Furthermore, this novel paradigm opens up several research areas which will be detailed below and that should be in focus for future activities.

### Joint service-network optimization

Also for delay-constrained IoT applications (e.g., industry-chain management), one of the key challenges is to guarantee the desired Quality of Service (QoS). Dynamic resource allocation schemes shall be designed to jointly consider service deployment and network status to the purpose of achieving adequate levels of user experience. Emerging paradigms, such as SDN (Software Defined Networking) and NFV (Network Function Virtualization), are considered as key enablers of 5G system to introduce flexibility in network and service functionalities. These support D2D communications as recently shown in [85], [86], [87]. However, the process of integration is still in its infancy. The evolution of D2D communications in 5G systems moves away from the current view of providing just bit pipes. In the forthcoming 5G systems, ProSe are expected to offer on-demand advanced services, such as protocol conversion, in-network processing, semantic data transformation, thus guaranteeing high degree of network and application interoperability.

### Efficient IoT service proximity discovery

Efficient procedures to minimize the cost of peer discovery in terms of energy and traffic exchange are highly recommended for battery-enabled IoT devices.

When accounting for their sensing, actuation, and data processing capabilities, appropriate abstraction layers shall be implemented to provide common understanding between interacting devices. The establishment of D2D communications should also guarantee the most suitable matching between user requests and available device capabilities, while considering wireless channel conditions and network load. Besides, to improve resource reusability in IoT scenarios [88], traffic routes could be properly selected for sharing common service links among multi-hop D2D paths. Another approach to enhance the IoT navigability is proposed in [89] where, based on social networking concepts integrated into the IoT, links are selected to exploit overall network navigability.

### Incentives for user participation

Classic cellular-based transmissions require a user subscription to the wireless network provider, whereas D2D communications are typically based on spontaneous cooperation between end-users where either reciprocal benefits are obtained or support is offered as a form of altruism. In this latter case, when users are actually rational in the sense that they pursue their own payoff, novel incentive mechanisms are a basic requirement for realistic implementations of any D2D-based solution. As an example, rational users may be willing to provide their personal device resources only if sufficiently rewarded for the additional power consumption this may require. These incentives may come in different forms according to the considered scenarios and the devices/users being involved. For instance, besides the intrinsic networking benefits introduced by D2D (e.g., energy savings, lower delay, higher capacity), also economic incentives and social-based incentives may be considered [90]. In the futuristic vision where users’ devices expose further capabilities, such as computation, storage, and sensing, in the *Anything-as-a-Service* paradigm, the above discussed challenge becomes even more arduous and critical for a successful implementation. Thus, network and service providers, as well as application developers, should design well-defined incentive schemes to stimulate user cooperation [91].

### Service provisioning with multiple operators and networks

The support of D2D and proximity services may require new complex modalities of interaction between different network and service providers. Users with subscriptions to different cellular operators should be allowed to reciprocally authenticate and cooperate. Furthermore, in absence of services provided by other intra-operator subscribers, a user can receive the requested services from subscribers of different operators, similarly to the case of roaming for network connectivity. Further challenges are linked to the extremely heterogeneous IoT ecosystem, composed of a large set of different scenarios, such as those where D2D and non-D2D devices coexist in the same coverage area. A further issue, pushed by the

heterogeneity in the requirements of IoT over 5G systems, is the dependence on cellular networks. This introduces additional challenges to integrate devices such as RFID tags and sensors that are part of the IoT. This is of high relevance in the IoT vision, where devices differ as a result of their diverse functionality and offered service and have the ability to interconnect and communicate anytime in a collaborative manner with any other device. Moreover, D2D communications within the IoT ecosystem involves devices that belong to network domains with different characteristics.

To give an answer to the mentioned challenges, some architectural solutions that can be envisaged are: (i) relying on a centralized third-entity node, e.g., a broker, which mediates cooperation among multiple operators and networks; (ii) promoting direct interactions between the interested operators in a distributed way; and (iii) defining inter-operator control information exchange via the device, which shall be temporary registered to the foreign operator as long as the user needs the service.

### Mobility support

D2D-based interaction is unpredictable by nature because the chances that the users meet each other and, as a consequence, establish a D2D connection are strongly influenced by their mobility patterns. This results in highly opportunistic contacts due to potential *mobility* of all involved user devices. Therefore, on the way to integrate the native support of D2D communication into the 5G system architecture, the effects of user mobility have to be thoroughly characterized as they may have a profound impact on the resulting system performance. Mobility-related parameters determine the individual D2D link performance (length, duration, throughput, etc.) and the overall D2D system performance. The resulting performance depend also on other factors, including the type of application running on top of the D2D links. Although supporting communication in dynamic scenarios is essential for seamless service provisioning, still a few works in the literature address the issues of mobile D2D communications. As an example, the impact of mobility and network assistance (i.e. allowing the network to relay the multicast signals) has been studied in [69] where solutions on how to optimize multicasting by choosing the optimal multicast rate and the optimal number of retransmission times are proposed. Noteworthy, in heterogeneous IoT scenarios, a service orchestrator can more efficiently distribute tasks among devices accounting for both the required time of task processing and estimated contact time interval between users, based on their mobility prediction [92] as the effects of mobility may be very different for alternative user movement patterns.

### Privacy and security issues

Another key issue, which could lag the large-scale adoption of D2D communications for proximity-based services, is the risk for privacy and security attacks. These aspects are also of utmost importance for IoT

applications, e.g., in scenarios where wearable devices interact with external entities to transfer personal health information. Similarly, in industrial automation systems, which rely on remote actuation control to trigger real-time operations, this is of high interest. As also discussed in [93], multi-hop D2D communication introduce potential security risks when not trusted relays are used to forward/aggregate data from multiple devices. Thus, novel reputation-based mechanism shall be included to identify and avoid malicious users. A viable solution may be to exploit social network relationships among users and device themselves [94] to provide a trustworthy D2D system [95].

## 6. Conclusions

In this paper, the potentialities of D2D communications for the Internet of Things are investigated. A broad overview of ongoing research and standardization activities for D2D communications technology in future generation systems is given. Particular attention has been devoted to possible use cases and benefits this technology may introduce to meet the manifold key requirements and open issues in the IoT. Finally, a look into the novel and futuristic visions of the IoT is reported. This highlighted the manifold challenges ahead of us and research directions that need further investigation to realize the full convergence of IoT in next-to-come 5G systems, where a device-oriented Anything-as-a-Service ecosystem is expected to be the reality.

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