what is in for D2D in 5G wireless
support of underlay low-rate M2M links

Petar Popovski

petarp@es.aau.dk
Aalborg University, Denmark
5G will not only be “4G, but faster”
5G research @ EU

FP7 METIS
Mobile and wireless communications
Enablers for the Twenty-twenty (2020) Information Society

Budget: 27 M€.

Objective: 5G by 2020

System concept that meets the requirements of the 2020 connected information society and extend today’s wireless communication systems to support new usage scenarios. Such a system has to be more efficient, versatile, and scalable compared to today’s systems.
METIS system concept

immense task, split into 5 Horizontal Topics

- **direct Device-to-Device communication (D2D)**
  how to efficiently enable and for what to use D2D

- **Massive Machine Communication (MMC)**
  how to support a massive number of low-cost, low-energy devices
METIS system concept

- **Moving Networks (MN)**
  extend the current wireless infrastructure to moving/nomadic nodes and create new services

- **Ultra-Dense Networks (UDN)**
  provide and sustain high rates to a large number of users in close proximity

- **Ultra-Reliable Communication (URC)**
  how to guarantee certain connectivity or latency 99.999+% of the time
a biased personal summary of 5G

R1: today’s systems
R2: high-speed versions of today’s systems
R3: massive access for sensors and machines
R4: ultra-reliable connectivity
R5: physically impossible
direct D2D

refers to **local** D2D communication controlled by the core network

it can potentially improve

- reliability
- latency
- throughput per area
- spectral efficiency
- machine-type access

new services
D2D for reliability

- extended coverage
  - multi-hopping
  - network coding
  - cooperative diversity

ad hoc networking in emergency
fallback solution
D2D for latency

- how to do this reliably in 2020+?
network-controlled D2D has an advantage over pure Bluetooth-like D2D

- facilitates **leader election** in neighbor **discovery** and link **rendezvous**
- interference control (licensed spectrum)
- diversified connection
offloading and local content sharing

close connection to **caching**

D2D for throughput
the D2D setting looks like a cognitive radio with consensual primary

- spectral efficiency in the previous example
- another example is to use the features of the multiple access channel
D2D support of machine-type access

trunking effect and coordination
decrease the random access pressure on the Base Station
D2D support of machine-type access

low power uplink

sensor attached to a phone

underlay operation in the same spectrum
D2D in the 5G diagram

- **data rate**: Gbps, Mbps, kbps, bps
- **offloading, prosumers**
- **machine-type access**
- **R1, R2, R3, R4, R5**
- **reliability, latency**

- **# devices**: 1, 10, 100, 1000, 10000
D2D for underlay machine-type access
scenario of machine-type D2D
model of underlay operation

Base Station
Cellular Device
Cellular MTD
Device-to-Infrastructure
Machine-Type Device-to-Device
Aggregate Interference \( \hat{I} \)
problem definition

assume that \textbf{\textit{B knows}} the channel \textbf{\textit{B-U}}

but \textbf{\textit{not}} the channel \textbf{\textit{M-U}}

\textbf{U} can decode both signals from \textbf{B} and \textbf{M}

how should \textbf{B} select the downlink rate \( R_B \), so that the \textbf{downlink} transmission is not in outage?
multiple access channel at U

low $R_{M0}$ candidate for interference cancelation
three MAC regimes with joint decoding (JD)

maximal decodable $R_B$

$R_{M0}$ not decodable

SIC: $R_{M0}$ removed first

joint decoding of $R_B$ and $R_{M0}$
\( \max R_B \) as a function of the strength of the link M-U

rates \( R_B \) and \( R_{M0} \) represented equivalently through SNRs \( \Gamma_B \) and \( \Gamma_M \)

\[
\Gamma_B = \frac{\gamma_B}{1 + \Gamma_M}
\]

possible to select \( R_B \) and avoid outage independently of the fading statistics for M-U
outage for the link M-U

below this value

\[ \frac{\gamma_B}{\Gamma_M} - 1 \]

outage affected only by the statistics of the M-U link

\[ \frac{\gamma_B}{\Gamma_B} - 1 \]
maximal zero-outage rate

\[ R_B = \log_2 \left( 1 + \frac{\gamma_B}{1 + \Gamma_M} \right) = C \left( \frac{\gamma_B}{1 + \Gamma_M} \right) \]

increases as the rate

\[ R_{M0} (\Gamma_M) \] decreases
a simple single-user decoder

\[ R_M \text{ is fixed} \]

\[ R_B \]

\[ C(\gamma_B) \]

\[ \frac{\gamma_B}{1+\gamma_M} \]

\[ C(\frac{\gamma_M}{1+\gamma_B}) \]

\[ C(\gamma_M) \]
maximal $R_B$ with single-user decoding

$$\Gamma_B = \frac{\gamma_B}{1 + \Gamma_M (1 + \gamma_B)}$$

maximal zero-outage $R_B$ is lowered, there is a penalty due to single-user decoding
evaluation scenario

- U is the reference point
- M is uniformly distributed on a unit-radius circle centered at U
- B and NM-1 MTDs uniformly distributed within the disk of radius R

\[
\sigma^2 = -97.5\,[\text{dBm}] \quad \alpha = 4 \quad R = 200\,[\text{m}]
\]
\[
P_M = -10\,[\text{dBm}] \quad P_B = 30\,[\text{dBm}]
\]
numerical results
regime of high interference
**summary**

D2D will play multiple roles in 5G and improve
- reliability, latency, throughput per area, spectral efficiency,

**machine-type access**

we have considered underlay D2D for

**low-power low-rate machine access**
- outage-free transmission even in presence of underlay
- keys: low rate and successive interference cancellation

**next steps**
- evaluate the concept with actual modulation/coding
- D2D for trunking in M2M access