Nanorod-based transparent electrodes as random resistor networks

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Summary

We have found that for number densities of sticks above the percolation threshold, the strength of the percolation cluster quickly approaches unity as the number density of the sticks increases; simultaneously, the percolation cluster becomes identical to its backbone plus simplest dead ends, i.e., edges that are incident to vertices of degree 1.
Our simulation suggests that, although the geometrical structure of the nanorod-based network is close to the prediction of Kumar et al. JAP (2017), the electrical conductivity is better predicated by the approach proposed by Forro et al.ACS Nano (2018) both for the wire-dominated resistance case and for the junction-dominated resistance one. Our computations suggest that the mean field approximation can be successfully applied when concentrations of fillers $n > 2n_c$. Estimates of the concentration of fillers corresponding to the optimum of FoM indicate that the mean-field approximation by Forro et al. ACS Nano (2018) is excellent appropriate for practical purposes, since the optimum falls on the concentration, when theoretical estimates almost coincide with direct computer calculations based on Kirchhoff's rules.

Motivation

Transparent electrodes are important components of modern optoelectronic devices such as touch-screens, heaters, and solar cells.
One of the most widely used kinds of transparent electrode consists of a transparent, poorly conductive film containing randomly distributed highly conductive elongated fillers such as nanowires, nanotubes, and nanorods.

Methods

We mimic nanorod-based transparent electrodes as random resistor networks produced by the homogeneous, isotropic, and random deposition of conductive zero-width sticks onto an insulating substrate. The number density (the number of objects per unit area of the surface) of these sticks is supposed to exceed the percolation threshold, i.e., the system under consideration is a conductor.
Kirchhoff's current law was used for each junction of sticks, and Ohm's law for each circuit between any two junctions.
To identify any current-carrying part (the backbone) of the percolation cluster, we have proposed and implemented a modification of the well-known wall follower algorithm —one type of maze solving algorithm.

Acknowledgements

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References

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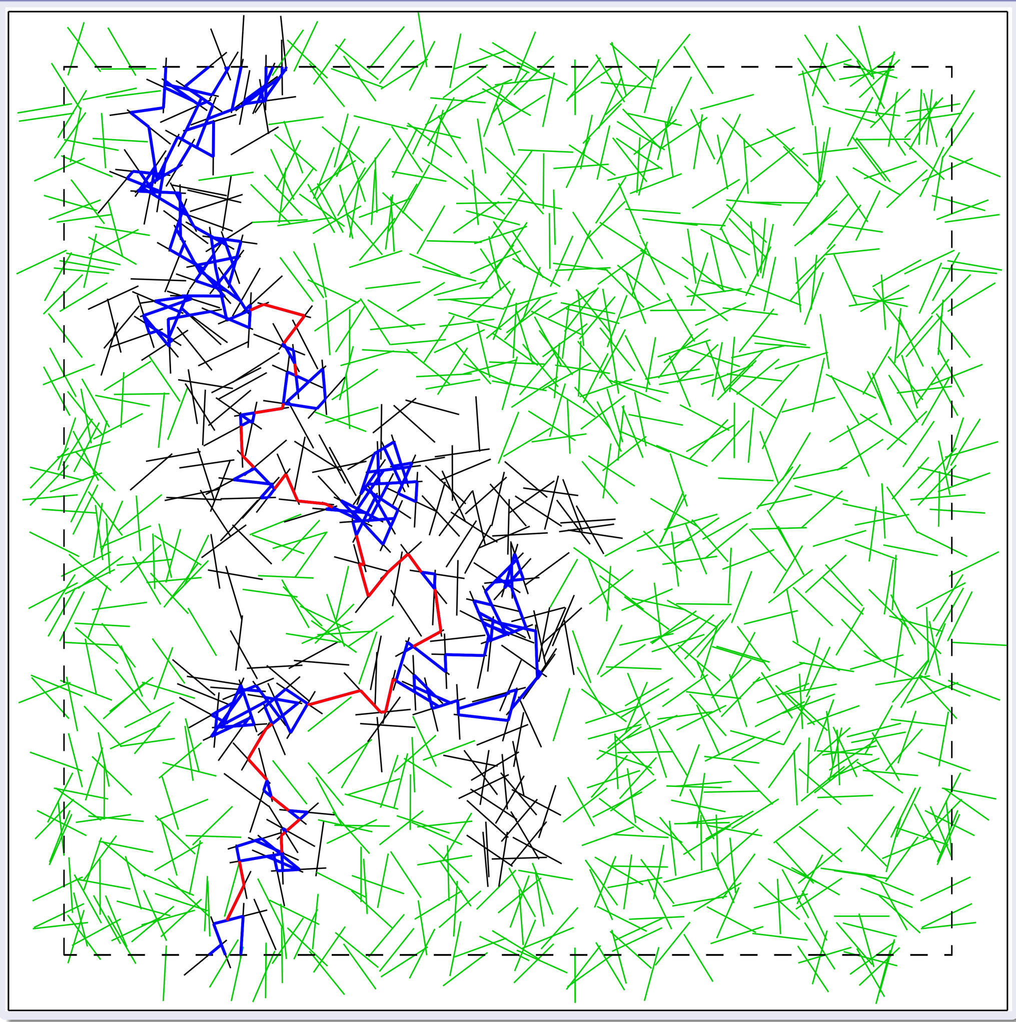
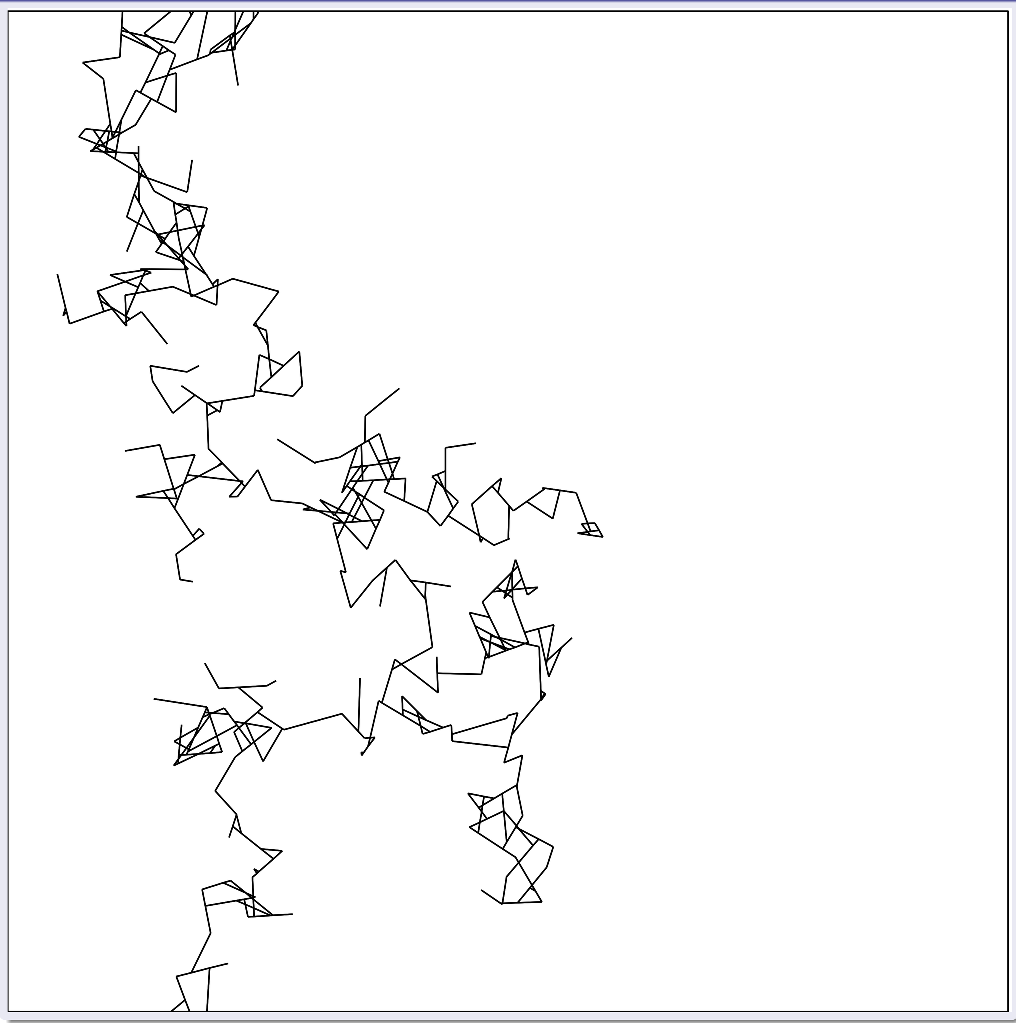
- C. Forró, L. Demkó, S. Weydert, J. Vörös, and K. Tybrandt, Predictive model for the electrical transport within nanowire networks, ACS Nano 12, 11080 (2018).
- Yu.Yu. Tarasevich, A.V. Eserkepov, R.K. Akhunzhanov, I.V. Vodolazskaya, M.V. Ulyanov Nanorod-based transparent electrodes: Identification of a current-carrying subset of rods using a modified wall follower algorithm arXiv:2103.05208 [cond-mat.stat-mech]

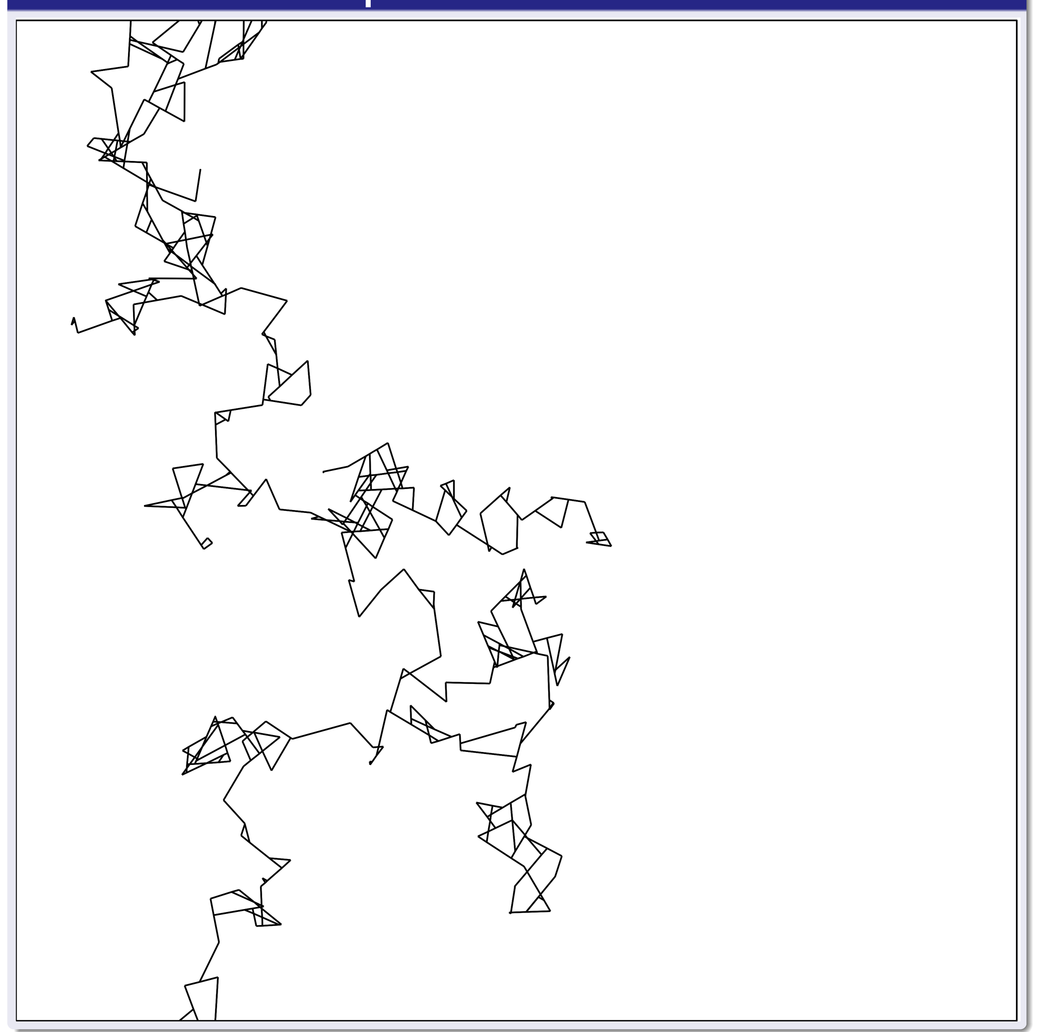
Example of the system under consideration



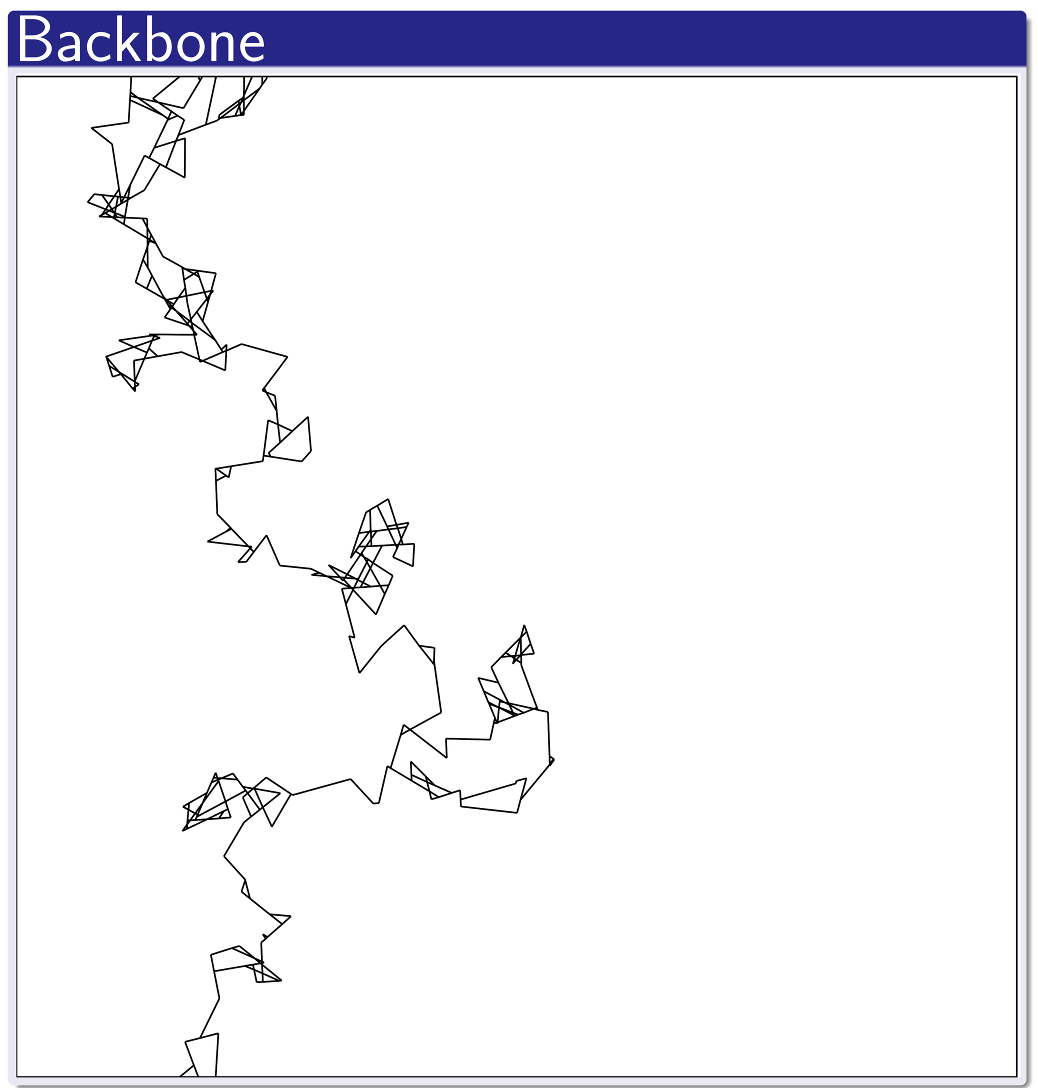
Approximate backbone



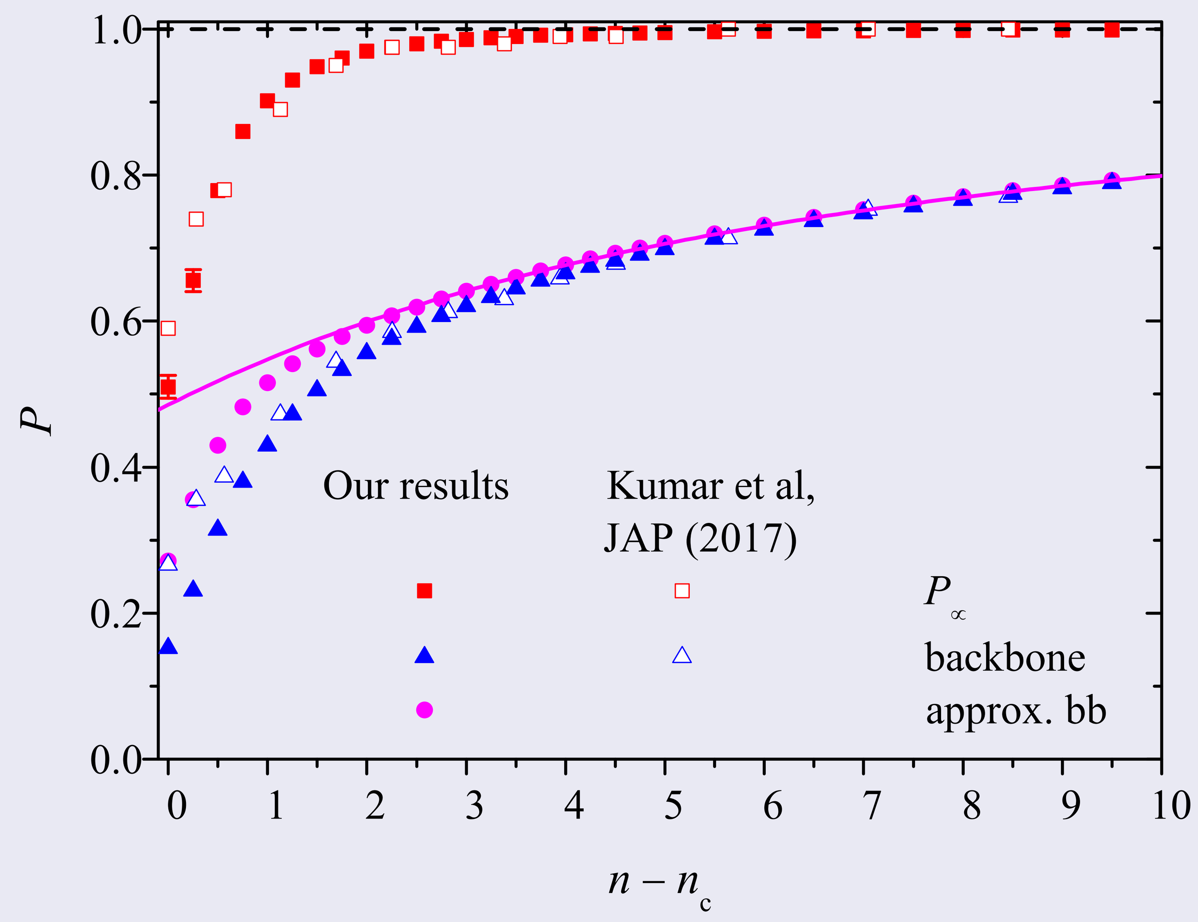
Backbone obtained by iteratively cut off of the simple dead ends



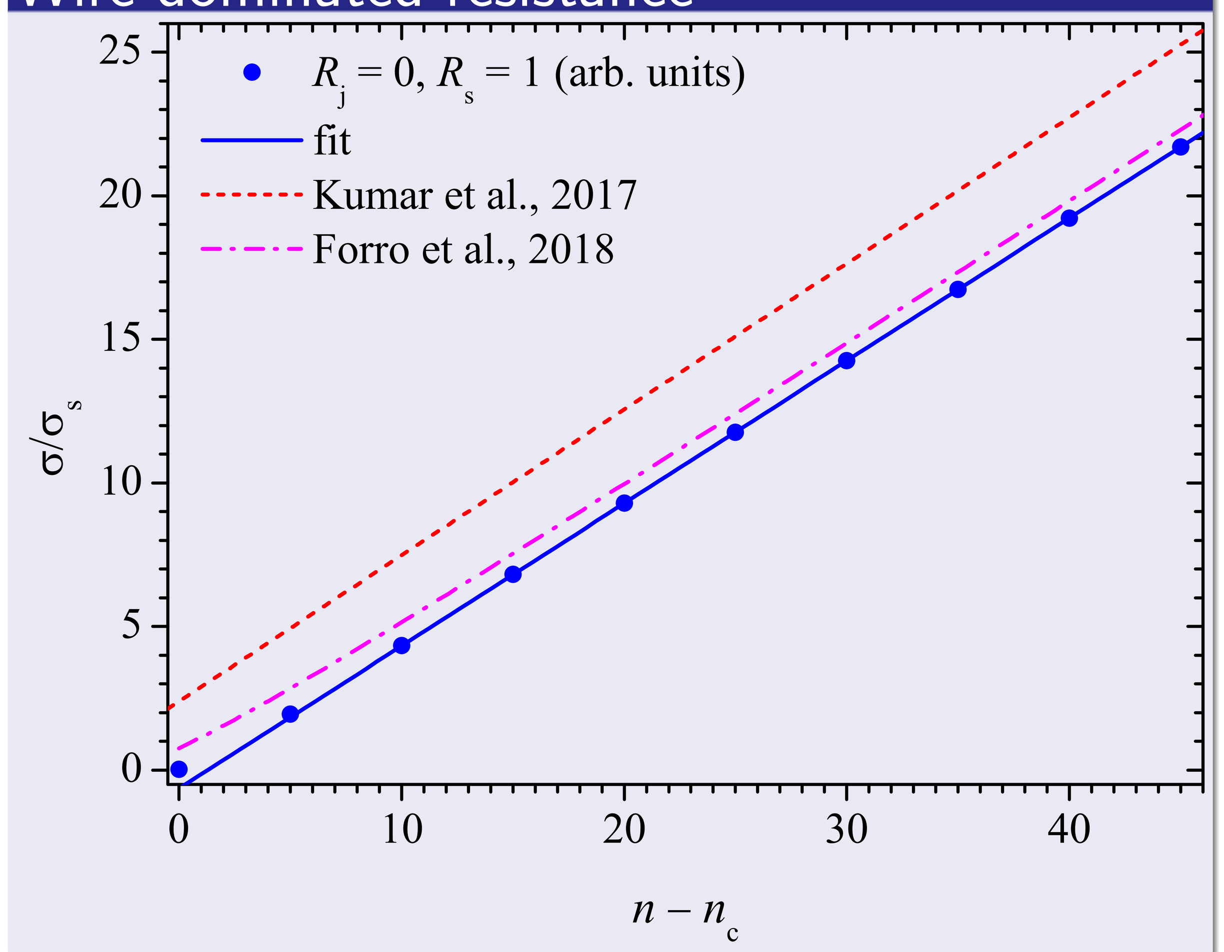
Backbone



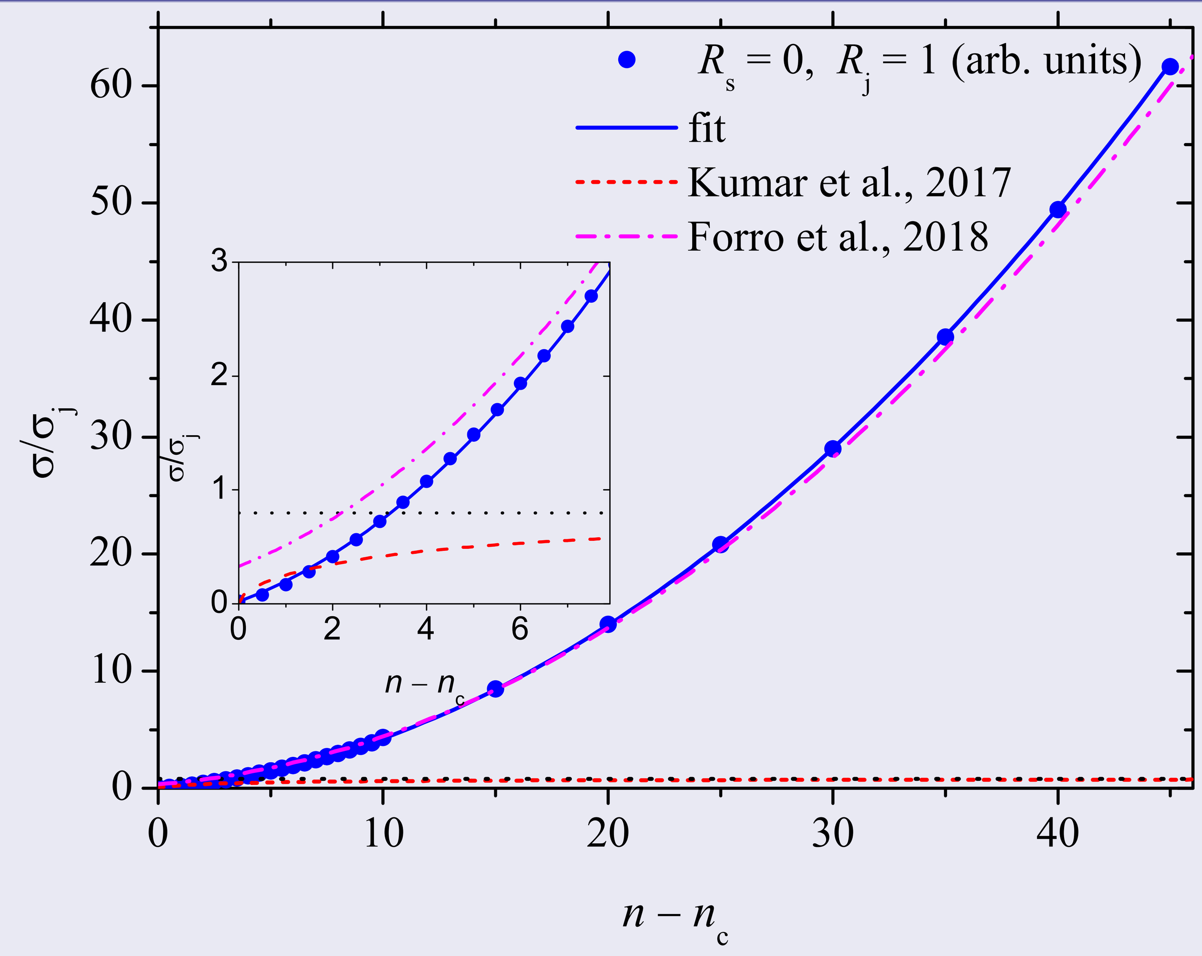
Strength of the percolation cluster and its backbone



Wire-dominated resistance



Junction-dominated resistance



Wire and junction resistances are equal