A novel 3D network single-phase Ni$_{0.9}$Zn$_{0.1}$O has been designed and synthesized by calcining a special metal-organic precursor (MOP) (MeO$_2$C$_3$H$_6$, Me=Ni and Zn, the molar ratio of Ni: Zn=9:1) as the self-sacrificing template for the first time. Comparing with NiO or the mixture of NiO and ZnO, the new two-step Li-ion storage mechanism in the 3D network single-phase Ni$_{0.9}$Zn$_{0.1}$O has been discovered and verified to be: a reversible conversion reaction between Ni$_{0.9}$Zn$_{0.1}$O and Ni-Zn alloy (Ni$_{0.9}$Zn$_{0.1}$), and a reversible Li-alloying reaction between Ni-Zn alloy and Ni$_{0.9}$Zn$_{0.1}$Li. More remarkably, due to the new mechanism, the anode material shows a low initial discharge platform around ~ 0.5 V (vs. Li$^+$/Li). The first discharge voltage is lower than typical transition-metal oxides, which generally have higher initial discharge plateau around 1.0 V (vs. Li$^+$/Li). It is shown that the novel 3D network single-phase Ni$_{0.9}$Zn$_{0.1}$O has outstanding electrochemical performances, demonstrating discharge capacities (e. g. 1465.3 mAh g$^{-1}$ at 100 mA g$^{-1}$ and 1055.6 mAh g$^{-1}$ at 800 mA g$^{-1}$, respectively), excellent capacity retention and superior rate capability (e. g. capacity retention ratio of 92.9% after 150 cycles at 800 mA g$^{-1}$ current density).